PRODUCTION AND EFFICIENCY AT ONTARIO UNIVERSITIES

PRODUCTION AND EFFICIENCY AT ONTARIO UNIVERSITIES:

EVIDENCE FROM DEPARTMENTS OF ECONOMICS

By

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ABSTRACT

The potential efficiency gains which could be realized at Ontario universities from system reorganization are analysed with special reference to departments of economics. A model of academic production is specified and estimated, and the results are used to perform various hypothetical experiments pertaining to the system rationalization proposal. It is found that, for departments of economics, an increase in research productivity, holding teaching output constant, would result from either producing output at fewer, larger departments, or by creating a two-tier system. However, the actual gain in productivity, or cost savings, which are predicted to occur, are surprisingly small. In general, the results of the analysis do not lend support to the notion that system rationalization would substantially solve the financial difficulties of the university system.

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CHAPTER 1

INTRODUCTION

1.1 Higher Education in Ontario

The system of higher education in Ontario comprises a substantial number of post-secondary educational institutions which differ greatly with respect to their objectives, educational technology, and funding. These institutions can be classed into four principal groups: Universities, Colleges of Applied Arts and Technology (CAATs), other government funded institutions such as the Ontario College of Art and Ryerson Polytechnic Institute, and private institutions. This study will focus exclusively on the university sector which consists of fifteen provincially chartered universities (Royal Military College, although technically a university, is excluded).

These fifteen institutions, listed below, differ in size and scope to a considerable degree. Some are principally concerned with undergraduate education while others offer postgraduate education in a wide variety of specializations. As well, most institutions "specialize" in certain areas, such as social science, natural science, or engineering. However, all of these institutions have the same general objectives, all are funded in the same manner, and all are organized in the same way.

Tables 1-1 to 1-3 below contain summary statistics on enrolment and academic staff for Ontario's fifteen universities for the 1979-1980 academic year. Tables 1-1 and 1-2 break total undergraduate and graduate enrolment into full-time and part-time enrolment for each university. Table 1-3 presents total enrolment, broken down into graduate and undergraduate, and academic staff at each university.

TABLE 1-1

Undergraduate Enrolment: 1979-80

University	Full-time	Part-time	Total
Brock	2,118	2,483	4,601
Carlton	7,370	4,993	12,363
Guelph	8,549	1,135	9,684
Lakehead	2,417	1,356	3,773
Laurentian	2,556	3,743	6,299
McMaster	8,778	2,796	11,574
Ottawa	10,580	5,596	16,176
Queen's	9,295	3,022	12,317
Toronto	28,562	11,137	39,699
Trent	2,110	1,267	3,367
Waterloo	13,251	4,462	17,713
Western	14,775	4,347	19,122
Wilfrid Laurier	3,234	2,528	5,762
Windsor	5,702	3,696	9,398
York	10,174	10,045	20,219
Total	129,461	62,606	192,067

Source: USIS - UAR system, Management Information Systems Branch, Ministry of Colleges and Universities, Ontario.

Tables 1-1 to 1-3 illustrate the substantial differences in size which exist between universities in Ontario. By far the largest is the University of Toronto with over 48 thousand students and 2,821 academic staff. The smallest is Trent University with only 3,408 students and 179 full time academic staff. Besides overall size, other differences emerge. For example, Trent University is devoted almost exclusively to undergraduate education. On the other hand seven universities, led by the University of Toronto, have graduate student populations exceeding ten percent of their undergraduate enrolment. Two universities, Brock University and Laurentian University, have more part-time students than full time students among both the graduate and undergraduate populations. This contrasts with the part-time to full-time ratios of about 1:2 for undergraduates and 11:14 for graduate students that exist for the province as a whole.

TABLE 1-2

Graduate Enrolment: 1979-1980

University	Full-time	Part-time	Total
Brock	49	426	475
Carleton	907	798	1,705
Guelph	646	129	775
Lakehead	109	119	228
Laurential	59	150	209
McMaster	1,121	782	1,903
Ottawa	1,243	1,579	2,822
Queen's	1,084	465	1,513
Toronto	4,711	3,978	8,689
Trent	33	8	41
Waterloo	1,084	594	1,678
Western	1,660	776	2,436
Wilfrid laurier	235	140	375
Windsor	492	495	987
York	1,222	1,254	2,476
Total	14,619	11,693	26,312

Source: USIS - UAR system, Management Information Systems Branch, Ministry of Colleges and Universities, Ontario.

TABLE 1-3

Total Enrolment and Full-time Academic Staff: 1979-80

University	Under-grad.	Post-grad.	Total	Staff
Brock	4,601	475	5,076	220
Carleton	12,363	1,705	14,068	625
Guelph	9,684	775	10,459	769
Lakehead	3,773	228	4,001	250
Laurentian	6,299	209	6,508	338
McMaster	11,574	1,903	13,477	912
Ottawa	16,176	2,822	18,998	1,002
Queen's	12,317	1,513	13,830	928
Toronto	39,699	8,689	48,388	2,821
Trent	3,367	41	3,408	179
Waterloo	17,713	1,678	19,391	800
Western	19,122	2,436	21,558	1,392
Wilfrid Laurier	5,762	375	6,137	213
Windsor	9,398	987	10,385	496
York	20,219	2,476	22,695	1,014
Total	129,067	26,312	218,379	11,959

Source: USIS - UAR System, Management Information Systems Branch, Ministry of Colleges and Universities, Ontario; Full-time Teaching Staff System, Statistics Canada.

In addition to the differences between universities with respect to the types of students taught the 15 universities differ significantly in their areas of specialization. To illustrate this, Table 1-4 presents the number of degrees granted, by level, in the Social Sciences at each of the 15 universities in 1979.

As this table demonstrates, some universities have a much stronger Social Science orientation than others. As well, a comparison of Tables 1-3 and 1-4 indicate that, as a percentage of total enrolment, some universities essentially specialize in the Social Sciences. For example, although York University ranks fifth in terms of full-time undergraduate enrolment and fourth in terms of full-time graduate enrolment it ranks first in Social Science Bachelor's degrees granted, and second in both Master's and Doctoral degrees granted. On the other hand, the University of Waterloo, which ranks third in full-time undergraduate enrolment ranks eighth in terms of Socal Science Bachelor's degrees granted.

TABLE 1-4

Degrees Granted: Social Sciences, 1979(1)

University	B.A.	M.A.	Ph.D.	Total
Brock	221	7	-	228
Carleton	840	218	19	1,077
Guelph	506	46	1	553
Lakehead	248	13	-	261
Laurentian	517	-	-	517
McMaster	1,024	205	18	1,247
Ottawa	1,050	230	28	1,308
Queen's	484	220	20	724
Toronto	404	476	65	945
Trent	325	6	-	331
Waterloo	583	63	12	658
Western	1,320	284	26	1,630
Wilfrid Laurier	739	97	-	836
Windsor	1,038	102	11	1,151
York	2,228	432	26	2,686
Total	11,527	2,399	226	14,192

Source: Special Reports, Statistics Canada.

Tables 1-1 to 1-4 illustrate that the 15 universities in Ontario

(1) It should be noted that the low number of B.A.'s granted by the University of Toronto reflects the differences in reporting definitions between the University of Toronto and other universities. At the University of Toronto, students studying traditional social science disciplines such as economics or political science, are granted a B.A. in Arts and Sciences.

differ greatly with respect to their size and 'product mix'. Despite their evident differences, there are strong reasons for regarding them as constituting a complete and distinct 'industry' for the purpose of analysis. Perhaps the most important reason for distinguishing these 15 institutions from other institutions of higher education in Ontario, or from other universities in Canada, has to do with the relationship which exists between the universities and the Government of Ontario, particularly with respect to the funding of the universities. This relationship will be examined in the next section.

1.2 The Role of Government in Ontario's Universities

Despite the differences, the 15 universities share the same stated objectives, the same institutional structure, produce the same set of products, and operate subject to the same set of constraints.

The Ontario Council on University Affairs (OCUA), a quasi-governmental advisory body which makes recommendations to the Ministry of Colleges and Universities, has specified these five goals for universities in Ontario:

1. to develop a more educated populace,
2. to educate and train people for the professions,
3. to provide for study at the highest intellectual level,
4. to conduct basic and applied research including development and evaluation, and
5. to provide public service. (OCUA, 1978)

These goals were subsequently adopted by the Ontario Government, the Committee on the Future Role of The Universities of Ontario (CFRUO) and the Commission on the Future Development of the Universities of Ontario (CFDUO), generally known as the Bovey Commission after its chairman Edmund C. Bovey (CFDUO, 1984, pp. 3). As the list of goals demonstrates, the university system is perceived to play a far wider role in society than simply the provision of a private service (education) to individual consumers (students). These goals indicate that universities also are expected to provide a public good in the form of public service to society as a whole. As well, the universities are expected to provide private services not just to students but also to government and industry in the form of basic and applied research. Finally, the objective of developing a more educated populace suggests that universities may be expected to generate external benefits to society over and above the private benefits enjoyed by individual consumers of the university's outputs.

The principal service provided by universities is education and the principal consumers of this service are students. That education is, in general, a private service which could be provided through the market mechanism is attested to by the existence of a sizable number of private educational institutions at both the secondary and postsecondary levels. That university education, in particular, can be provided by the market mechanism can be attested to by the existence of private universities, some of which are of the highest quality, in other countries.

Nevertheless, the existence of public good outputs and external benefits of university production constitute an argument and justification for the role of government in the provision of university outputs. In addition, two further reasons for a governmental role in university affairs exists. The first is the perceived ability of universities to perform an income redistribution function. The argument is that a university education represents, at least in part, an investment in productive human capital. (This argument is examined in greater detail in Chapter 2.) However, in the absence of a perfect capital market low-income students will not have access to funds to acquire a university education while high-income students will have access to the requisite funds. In the absence of government involvement the university system would perpetuate existing income differentials. On the other hand, should the government make university education affordable to all potential students, regardless of their family income, existing income differentials would be narrowed as talented students from poor families acquire human capital. This rationale has been recognized and incorporated into government policy in Ontario for many years under the oft stated goal of 'accessibility'.(1)

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(1) Accessibility has been a government policy in Ontario for over 25 years. For example the OCUA stated in its sixth annual report (March, 1980) that "accessibility has been a Government policy for several years and Council assumes that it will remain a stated objective of Government" (pp. 60). One of the earliest and clearest statements on accessibility came in 1959: "Our objective is to insure that no student who has the capacity will be deprived of the opportunity of attending university and developing his talents to the fullest possible extent" (Honourable J. N. Allan, Februrary 23, 1959, Legislature of Ontario Debates). In 1984 the Bovey Commission, in reference to the policy of accessibility stated: "We believe . . . this policy remains valid (CFDUO, 1984b, pp. 8).

Finally, the last reason that governments may wish to involve themselves in university affairs is to provide some form of quality control. Normally, of course, quality control is the function of individual firms. Firms who produce poor quality products or services can expect to suffer reduced demand for their product. However, in certain instances, presumably when public saftey is at stake, or where significantly imperfect knowledge on the part of consumers exists, the government may wish to undertake the role of grading or certifying products. The fact that the Government of Ontario effectively certifies programs offered by universities offers prima facie evidence that some such quality control role is implicity undertaken by the government.(1)

The forgoing discussion offers several standard economic justifications for an active governmental role in the provision of university outputs. Some commentators offer a more self-serving rational for governmental involvement. "Universities therefore became another form of government largesse to be laid before a grateful flock of voters" (Bercuson, Bothwell and Granatstein, 1984, pp. 17-18). Whatever their motives, both federal and provincal governments have had some role in financing universities since the 1940's when veterans' retraining institutions were paid subsidies by the federal government.

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(1) For example, in order to be deemed eligible for formula support for new graduate programs, universities must first receive ministerial approval which requires, among other things, "Certification from the Advisory Committee on Academic Planning through the Council of Ontario Univeristies that the proposed program has passed a rigorous appraisal and at the time of appraisal was not found to require improvements" (OCUA, 1980, pp. 82).

Assistance for university students pre-dates direct grants to institutions with the introduction of provincial scholarships in 1920. Formula-type funding began in 1951 after the publication of the Massey report, and the present approach was adopted after 1966 and has been in effect since then (Harris, 1976).

TABLE 1-5

Total Revenue by Source 1979-1980 ($000)

University	Prov. Grants	Tuition Fees	Spons. Research	Other	Total
Brock	13,040	2,716	823	2,660	19,239
Carleton	40,201	7,999	5,483	10,720	64,403
Guelph	48,680	7,534	25,039	21,417	102,670
Lakehead	13,877	2,586	1,060	3,924	21,447
Laurentian	17,479	3,035	988	3,695	25,179
McMaster	53,190	8,542	22,863	20,311	104,904
Ottawa	63,871	10,566	10,372	15,732	100,541
Queen's	53,988	8,944	12,923	24,079	99,934
Toronto	172,186	27,488	48,452	54,015	302,141
Trent	8,823	1,889	575	5,118	16,405
Waterloo	58,144	11,787	10,350	18,819	99,100
Western	75,752	12,619	18,422	31,262	138,055
W.L.U .	14,169	3,731	211	6,189	24,300
Windsor	35,003	6,977	3,033	6,746	51,759
York	60,709	13,532	5,439	16,583	95,961
Total	728,810	129,965	166,033	241,270	1,266,038

Source: Ontario Ministry of Colleges and Universities
Statistical Summary, 1979-1980

At present, universities derive their revenue from five basic sources: Formula grants, non-formula grants, tuition fees, sponsored research, and other sources. The other sources include gifts, interest on capital holdings, and fees for services. The latter can be quite substantial if, for example, the university has a medical school where faculty engage in private practice and are obliged to pay some of the fees thus generated to the university.

As Table 1-5 indicates, the Provincial government is the primary source of financing for Ontario's universities. As well, the universities represent a major category of expenditues on the part of the Ontario Government. For 1979-1980, total provincial expenditure on universities in Ontario, including operating grants, capital grants, provincial contributions to sponsored research, and direct aid to students, amounted to nearly one billion dollars (OCUA, 1980a).

1.3 Financing Problems Facing the University Sector

The institutional arrangements by which universities are funded in Ontario and the resulting massive public investment in the university system have naturally resulted in the provincial government and the universities taking on adversarial roles. Since the universities are proscribed from raising tuition fees they must acquire funds to meet increased funding requirements from the provincial treasury or by raising money through contributions from private donors. Since the provincial government has a desire to control spending, the level of financial support for universities has not kept up with the universities' perceived needs. Indeed, the level of financial support per student has actually declined in real terms since 1971. In fact, between 1974-75 and 1981-82, Ontario's Provincial operating grants per student had fallen from fifth to tenth among the ten provinces (Tripartite Committee on Interprovincial Comparisons, 1982).

The Commission on the Future Development of the Universities of

Ontario has identified six factors which have contributed to the stress which has increasingly grown up between the univerities and the government. They are:

> "1) the slower growth in the per capita wealth of the country, which makes public funding of new projects or expansion of existing programs difficult;
>
> 2) the increasing demand for specialized research and development based within the university system and for highly qualified manpower in specialized areas;
>
> 3) the need to adjust a faculty base developed during a period of expansion, to a more stable base in the number of students, together with measures which will take into account the age distribution of faculties in relation to present and future needs;
>
> 4) the need for funding arrangements which will more adequately reflect the different functions of the universities;
>
> 5) the attempt to meet faculty expectations and appropriately reward faculty in a period of change and straitened resources, and;
>
> 6) the cardinal role of universities in the development of new knowledge in scientific and technological fields and in relating this development to its impact upon society and human values." (CFDO, 1984b, pp.4)

However, from the point of view of the universities, the fundamental problem they face is one of underfunding. "For at least the past six years the universities in Ontario have been arguing strenuously that they have been underfunded, and they have produced a substantial amount of data in an attempt to support that proposition. For its part, the Government does not appear to have accepted this argument." (Skolnik and Rowen, 1984, pp. 133)

1.4 Three Proposals

The problem described above is quite straightforward. Over time Ontario's universities have become almost totally dependent on Provincial funding. The provincial government has, over the past several years, decided to impose financial restraint on the universities, but without providing any real direction for the universities to follow when applying restraint to their operations. The universities claim that the result is underfunding and a resultant fall in the quality of education and research and a deterioration of the effects of the policy of accessibility. "If the Ontario Government's goal of balancing the provincial budget by 1983-1984 remains the overriding factor in the determination of grant levels, and priority accorded the universities remains the same, there will be increasingly severe difficulties in these institutions. Worse still, it will not prove possible to maintain the present quality and range of educational opportunity in Ontario". (OCUA, 1980b, pp. 37) The government, on the other hand, has apparently not accepted the position of the universities and instead appears to be searching for ways in which the university system could be restructured to ensure continued accessibility and quality but without an increase in real resources.(1)

Out of the debate between the universities and the government

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(1) See for example; The Honourable Bette Stephenson's statement to the Legislature on the establishment of the Commission for the Future Development of Universities in Ontario, December 15, 1983.

over financing has come a series of papers and proposals. Of those, four may be regarded as crucial in the development of the debate. The first of these was an OCUA white paper published in September 1979 and entitled "System on the Brink". In that paper the OCUA first made its strong case for improved (i.e., increased) funding and examined the implications of continued underfunding. They conclude that the funding shortfalls would result in reductions in faculty positions or real salaries which in turn would have a serious effect on "the quality and range of educational opportunity and on the universities' research function" (OCUA, 1980, pp. 29). The second crucial paper came the following year with the publication in 1980 of an OCUA paper entitled "System Rationalization" in which it was argued that one way to deal with reduced resources was through role differentiation, and program elimination. The third important event came a year later with the final report in August, 1981 of the Committee on the Future Role of Universities in Ontario (CFRUO) which had been established a year earlier by the government. Its recommendation for dealing with limited resources was for a restructuring of the university system which "would include reducing the number of universities, changing the character of some or all of the universities and limiting their range of activity, and grouping universities into two or more categories with different missions" (Skolnik and Rowen, 1984, pp. 129). Finally, three years later in December, 1984, came the final report of the Commission on the Future Development of the Universities of Ontario (CFDUO). This commission made 51 separate recommendations which included the proposal that tuition should rise to meet 25% of total educational costs and that universities which receive relatively large amounts of federal research grants should be designated as research intensive institutions and should receive extra provincial support on that account (CFDO, 1984, pp. 39).

An analysis of the debate over university funding in Ontario and the various proposals which have been put forward suggests that the positions of the OCUA and the various government-appointed commissions are based on some underlying and unstated notions about the nature of academic production. Specifically, all of the contributions to the debate discussed above are based on a basic production model in which inputs are transformed through the application of technology into outputs. In addition, all of the proposals for restructuring the university system are implicitly based on assumptions about the nature of that production process. For example, why reduce the number of universities? Only if larger universities are more economically efficient than smaller ones does it make sense to close universities. This is true even if the university closures are intended to cope with reduced enrolment rather than to handle current enrolment levels more efficiently. The same argument applies to closing departments while maintaining the same number of universities (which can be included as part of the program elimination discussed by OCUA). This can only make sense if there is some size of department which is more efficient than some other size, for if all sizes of departments are equally economically efficient the number of departments does not matter, only the total level of outputs produced. As another example, why propose that certain departments or universities specialize in certain activities? Again the answer can only be that an assumption is being made about the underlying nature of the production process.

In order to examine the relationship between the production process and possible solutions to the funding crisis at Ontario universities, three specific proposals will be evaluated and compared. These three proposals have either been explicitly suggested by one of the participants in the debate, or at least are within the framework of proposals examined above. Each could be considered a serious proposal. In addition, an examination of the three proposals will provide evidence on the potential efficacy of various other proposals which depend implicitly on similar assumptions about the nature of academic production.

The first proposal that will be examined is one that has been part of the discussion since at least 1980. This proposal is to create a two-tier system of universities in Ontario, with Tier-One universities being oriented towards graduate teaching and research, employing faculty members with high research skills, and having low undergraduate teaching loads, while Tier-Two universites would specialize in undergraduate teaching, not be expected to perform research, and not have graduate programs. It should be noted that this proposal, while generally couched in terms of two tiers of universities, might also apply to two tiers of departments. In other words one university might have a Tier-One Physics department and a Tier-Two Sociology department. This latter approach of two tiers of departments has the advantage that no one university need be totally relegated to the second tier and that implimentation could follow along the lines of established strength. As such it is more in line with the OCUA's system rationalization approach than with the Bovey commission's approach which wants to identify "institutions" that would be research intensive.

The second proposal that will be examined has similarly been much discussed. This proposal is simply to close individual universities (as happened in British Columbia with Notre Dame University) or to close whole departments, in which case a university which now has a department of (say) Business would no longer have one. In the case of this proposal most of the attention has been with the closure either of whole universities or of semi-professional programs, such as education or architecture, since departments in traditional arts and sciences disiplines provide service functions for other departments, and thus a university could not function without them.

The first two proposals will be examined on the assumption that the objective of the proposals is to go to a more efficient system of production so that the same levels of outputs could be generated with fewer resources and thus at less cost. However, the results of the analysis can apply as well to the situation in which the proposals are viewed as ways in which to minimize the lost output resulting from a reduction in inputs. In order to provide some basis for comparison the third proposal which will be examined is for the overall levels of inputs to be reduced in at least some disiplines while maintaining the status quo in terms of the structure of the university system as a whole. In a sense this represents a proposal to continue underfunding without any restructuring. In that case universities would be forced to reduce either the number of faculty members employed or hold down salaries and equipment and thus loose top researchers to other jurisdictions. In either case, the levels of inputs would fall and the results would have to be a reduction in students taught or (more likely given the funding formula) a reduction in research output.

1.5 Objectives of the Thesis

In a 1966 report sponsored by the Canadian Association of University Teachers (generally referred to as the Duff-Berdahl report, after its authors Sir James Duff and Robert O. Berdahl) it was suggested that "in a university . . . productivity simply is not measurable" (Canadian Association of University Teachers and the Association of Universities and Colleges of Canada, 1966, pp. 21). Yet, as demonstrated above, the debate over the future of Ontario's universities has been based on the notion that some ways of organizing universities are more productive than others, in other words that there is a production process that transforms inputs into outputs, and that the process can be characterized. The objective of this thesis is to specify and estimate a model of university production and to use the results to evaluate the three specific proposals discussed above.

1.6 Outline of the Thesis

In the following seven chapters the basic model will be specified and estimated using data on departments of economics in the academic year 1981-82. In Chapter 2 the conceptual and operational difficulties involved in defining the inputs and outputs of university production are examined. Chapter 3 discusses the problem of modeling the university based on existing economic models of the firm while Chapter 4 presents the specific model on which the results of this study are based. In Chapter 5 the production function for university research is estimated using data drawn from departments of economics. In Chapter 6 the results of this analysis are then used to evaluate each of the three policy proposals with respect to the potential efficiency gains or cost savings that could be realized in departments of economics from implementation of these policies. In Chapter 7 the sensitivity of the results to the operational definitions of the variables and the data collection procedures is tested. As well an analysis is undertaken to determine the degree (if any) to which the results of the analysis in Chapters 5 and 6 can be generalized to disciplines other than economics. Finally, Chapter 8 presents the summary and conclusions.

CHAPTER 2

INPUTS AND OUTPUTS

> "The crucial problems consist of measurement of the outputs and inputs, the valuation of them, the specification of tractable production relations, and the specification of the extent to which decentralized units within the university can be assigned their own decision rules". (Bear, 1974)

2.1 Introduction

It might be argued that the 'crucial problems' identified by Donald Bear are simply those which are central to any study of economic production and would apply to an economic model of steel production just as well as to an economic model of university production. While it is certainly true that the successful resolution of these issues is crucial to any production study there are few industries where their resolution is so problematic. Indeed it could be argued that in the case of universities these questions are inherently unanswerable and thus no economic model of universities is possible. It is the position of this thesis that while these problems are difficult, and no perfect answers can be found for many of them, an economic model of university production is possible and fruitful. In the remainder on this chapter the conceptual and operational difficulties involved in the definition of the inputs and outputs of university production will be examined. Chapter 3 will examine the issues of specifying tractable production relations and determining the unit of analysis.

2.2 Outputs: Introduction

As described in Chapter 1, Ontario's universities operate under provincial charter, obtain most of their funding from the public purse, and are non-profit organizations. As such, they share many characteristics with other publicly funded non-profit organizations such as hospitals, art galleries and museums. One of the distinguishing characteristics of such organizations is that the questions of what the organizations should produce, and what they do, in fact, produce are problematic. Central to the problem of understanding exactly what it is that these institutions are producing and what it is that they should be producing are three considerations. First, such institutions produce services which, by their very nature, are intangible and not easily susceptable to physical measure. Second, since these institutions do not operate within 'normal' markets, the use of market valuation of these services is made difficult. Third, these publicly funded non-profit organizations tend to produce outputs which exhibit some degree of publicness. (It was noted in Chapter 1 that the alleged publicness of university outputs was one justification for public funding.) This adds to the difficulty in definition and measurement.

The existing literature on the output of universities has discussed and evaluated a large number of possible definitions of university output, both from a normative and a positive standpoint (See for example; Archibald, 1974; Hettich, 1971, 1972; Very and Davies, 1974; or Garvin, 1983). However, from both standpoints two outputs are considered central: teaching and research. The theoretical and operational difficulties of defining these two outputs will be discussed in sections 2.3 and 2.4 below. Section 2.5 contains discussion of university outputs other than teaching and research.

2.3 The Teaching Output

In attempting to arrive at a meaningful definition of the teaching output of universities the logical place to begin is probably with a student-based measure, i.e., a measure based on the number of students taught. Student-based measures might include total enrolment per year, total enrolment in various programs per year (e.g., total enrolment in political science at the Bachelor's level), or total number of degrees granted per year. Which of the many possible student-based measures is chosen will depend on the specific purpose to which it is to be put, but all such measures share certain common advantages and disadvantages. A logical and natural approach to measuring any service is with the number of individuals served. Thus the output of a barber shop might be measured by customers served, that of a telephone exchange might be measured by calls handled, and that of a university might be measured by students taught. This is especially true in the case where the service rendered (in this case the teaching) is thought to be constant for all individuals served across all institutions rendering the service. On the other hand, this approach suffers from the following disadvantage: Any student-based measure will be invariant with respect to the technology of production. In other words, what students are taught and how they are taught will have no effect on measured output. Using this approach, it would appear that the most 'productive' technology would be one that minimized the number of professors and physical plant per student (i.e., a degree-mill). This example highlights one of the major objections to using a student-based measure of teaching output. Students are not the output of universities per se, but rather it is the addition to the human capital of students that is the true output of the teaching process. It should be noted that this objection is not specific to the university example but is one which will always apply to measuring the output of a service by the number of individuals served. There are three ways in which this objection can be dealt with.

First, the actual output embodied in the student-based measure can be assumed constant across all units of analysis. Thus, if it can be assumed that all university degrees at a given level of disaggregation (say all bachelor's degrees in physics granted by an Ontario university in 1980) embody identical augmentation of human capital this objection is negated. Depending on the level of disaggregation chosen this assumption may or may not be tenable. For example, one would hesitate to say that the University of Toronto produced 14.2 times the teaching output that Trent University produced in 1979-1980 simply because total university enrolment at the University of Toronto was 14.2 times that at Trent University. Trent University specializes in undergraduate teaching, with 99 percent of all enrolment at the bachelor's level while fully 20 percent of the University of Toronto's enrolment was at the Master's and Doctoral levels. Furthermore, the product mix of subjects taught is markedly different between the two universities. On the other hand, it makes much more sense to say that the teaching output of York University's law program decreased marginally between 1981-82 and 1982-83 when enrolment fell from 948 to 937 since the value added per student is likely to be essentially the same in both years. Thus while a student-based measure can be used, it must be used with care.

The second way in which this objection may be dealt with is by a direct attempt to measure the increase in human capital that comes about as a result of the teaching process. While there are a number of approaches which can be used to attempt to measure teaching output as the increase in human capital in students, all such approaches face the major difficulty that human capital may be inherently unmeasurable. Perhaps the most direct approach would be to devise some measure of cognitive ability and apply it to students both before and after the teaching process. This approach is favoured by those researchers attempting to estimate production functions for human capital production.(1) However, a quick overview of the literature in this area will indicate that the approach is far better suited to the measurement of teaching in primary schools, and even then only for specific skills like reading or verbal comprehension. Even if reliable and valid tests of cognitive ability could be developed for university level cognitive

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(1) The literature on educational production functions is vast. Two representative studies are Lau (1979) and Hanushek (1979). Although most of these studies deal with primary or secondary education, see Attiyeh and Lumsden (1974) for an attempt to specify production functions for universities.

skills and knowledge, it is by no means clear that the output of university teaching could be isolated as some combination of a finite number of cognitive abilities. Indeed it seems more plausable to say that the output of university teaching is a vector of various attributes, some of which might be measured as acquired ability in specific skills, but most of which could not be so measured.

One researcher who has worked along these lines is Archibald (1974), who defines the output of university teaching as being a four-tuple in which a given student-based measure (say degrees granted) at a given university consists of the following four attributes:

1. a consumer durable
2. a private investment good
3. a social investment good
4. a non-durable consumer good

Attribute 1, a consumer durable, refers to the human capital acquired which yields a stream of consumer services over time in the same way as a washing machine or automobile does. This is simply a more formal way of stating that one of the attributes of a university education is that it enhances the student's future enjoyment in life. Archibald goes on to suggest that this attribute is a particularly important aspect of an education in the Humanities and Arts, while less so in professional programs.

Attribute 2, a private investment good, refers to the human capital which yields a stream of income over time in the same way that any physical investment yields an income stream. Just as the value of physical capital is the expected present value of the income stream generated by the capital so too could the value of the acquired human capital be measured as the expected present value of the increase in lifetime earnings attributable to the education acquired.

The third attribute refers to the human capital which generates utility or income for individuals other than those receiving the university education. The argument is that a pool of highly educated individuals in society improves the growth, productivity, and income of the economy and thus contributes to the welfare of all individuals in that society.(1) It has also been argued that there are social externalities in the form of increased public awareness of social issues and improved citizenship which result from a highly educated populace.(2)

Finally, the last attribute, that of a non-durable consumer good, refers to the value of a university education as current entertainment service. It has been argued that some degrees have no real value as an investment good and thus the demand for an education in such a subject must be totally of a consumer good nature (Archibald, 1974).

This attribute approach has a number of theoretical advantages as a conceptual method of defining the output of university teaching.

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(1) The path-breaking work in this area is Denison (1962), which lead to the later human capital work of Becker (1964) and others.

(2) This is a standard argument which can be found in many undergraduate text books, see for example Cohn (1972); although it is more commonly applied to primary rather than post secondary education.

One of the important advantages of this approach is that the output (as defined) is no longer invariant with respect to the method of production. Thus it is possible that by (for example) increasing faculty/student ratios and thus lowering average productivity as measured in terms of degrees a department may actually be increasing the average productivity of faculty in terms of the values of the attributes embodied in the degrees. Thus the move towards higher faculty/student ratios at Ontario's universities which was noted by Hettich (1971) may represent an increase in productivity rather than the decrease which Hettich infers.

Unfortunately the theoretical advantages of this approach are more that counterbalanced by the extreme practical difficulties involved in trying to measure these attributes. Of all the attributes mentioned by Archibald the one most susceptable to measurement is the second one, that of a private income-yielding investment good. Based on the human capital approach developed by Becker (1964) and others, a number of studies have been attempted to measure the present value of a university education in a particuar field. (For Canadian studies see Handa and Skolnik, 1972 or Handa, 1975). The other three attributes are much less susceptable to measurement, although Lazear (1977), for example, has attempted to divide the value of higher education into investment and consumption components.

The third way in which the teaching output of universities could be measured without facing the difficulties which are endemic to a student-based approach is one which is often used to measure the output of other services, and that is to use the market valuation as a measure of output. The major difficulty with using customers served as a measure of the output of any service industry is that unless the quality of the service performed is constant the measure is flawed. However, if a market for the output exists, the value of services performed will reflect the differences in output. It could be argued then, that in a system in which the price of teaching services is set by a well functioning market, the university's tuition revenue could represent the teaching output. However, as explained in Chapter 1, in Ontario, tuition levels are effectively set by the provincial government and are arbitrary. Under these circumstances this approach would be inappropriate.

As the above discussion has illustrated, the problem of defining the teaching output of universities does not yield a single solution but rather several approaches, any one of which might be used. The approach which is chosen will depend on the purpose to which the the definition is to be put and the institutional structure within which the study will be undertaken. For example, a student-based measure such as degrees granted or total enrolment would be the appropriate approach for a study that assumes the attributes of the relevant student-based measure (say, a Bachelor's degree in sociology) are constant throughout the study. This implicit assumption is the basis of cross-sectional departmental cost studies. In these studies it is (implicitly) assumed that the attributes of the degree in question are constant across all universities in the study.(1) It should be noted that the studies referred to above use data on American and British universities where this assumption is much less likely to be accurate than it would be in Ontario. One of the caveats which must be clearly understood with respect to studies based on this assumption is that the results obtained, usually estimated cost functions, are not valid for the production of other degrees, the production of the same degree at a different set of universities, or even the production of the same degree at the same set of universities over a different period of time. The results only apply to the production of degrees containing the same vector of attributes and cannot in any way be generalized.

Because of this, student-based measures cannot be used in any circumstance where the vector of attributes cannot be assumed constant across all elements of the study. Thus student-based measures should not be used to perform cross-sectional studies where the unit of analysis is the university as a whole, nor can they be used in cross-sectional studies where the unit of analysis is a particular department if the universities in the study vary with respect to the content contained within a particular degree granted. What, for example, would be the meaning of a cost function for the production of Bachelor's degrees in psychology if half of the universities in the

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(1) For example, James (1978), Tierney (1980), Brinkman (1971), Very and Layard (1975). For a survey of early Canadian studies see Proulx (1973). As Stager (1982) points out, most Canadian cost studies were undertaken early in the last decade and little work has been done since.

study had departments which specialize in experimental psychology and half had departments which specialize in clinical psychology? Finally, student-based measures cannot be used for time-series studies unless the researcher is confident that the measure embodies the same vector of attributes throughout the the length of the study. Thus, for example, Hettich's (1971) previously mentioned finding of rising faculty student ratios in Ontario's universities between 1956 and 1967 can only be interpreted as falling productivity if the content of university degrees was the same in 1967 as it was in 1956. Otherwise no meaning can be attached to the findings (other than a purely descriptive one).

In cases such as these, where student-based measures are inappropriate, it becomes necessary to attempt to value the attributes embodied in the degree. One example of the type of research in which this is necessary is the estimation of the demand by students for various degrees or for the same degree (say engineering) over time.(1)

Ultimately then, a study of university production has but two choices, either define the unit of analysis carefully enough so that the student-based measure may be assumed homogeneous, or attempt to value the attributes contained within the measure (assuming a well-behaved market for teaching output does not exist). This study will take the former approach of choosing a student-based measure appropriate to the unit of analysis and the objectives of the study. The definition of the

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(1) Dodge and Stager (1971) is one such study which focuses on engineering.

measure used, along with the definitions of all other variables used in the study, will be described in Chapter 4.

2.4 The Research Output

The previous section has demonstrated that severe difficulties exist in trying to define the teaching output of universities. However, these difficulties are no more severe than the difficulties attendant on the definition of the research output. In fact it is probably correct to say that defining the teaching output involves operational difficulties while defining the research output involves both conceptual and operational difficulties. In general terms, research can be thought of as an activity designed to increase the stock of knowledge in society, just as teaching, in very general terms, can be thought of as an activity designed to increase the stock of knowledge in students. But while in the latter case the students taught form a natural point of departure, there is no corresponding measure of 'individuals served' in the former case. Indeed it should be recognized at the outset that research, by its very nature, cannot ever be subject to a direct measure. Instead, attempts to measure the level of research activities must focus on appropriate proxies. Four different approaches have been suggested in the literature. Each has its advantages and disadvantages.

The first approach, suggested by Archibald (1974), is to measure the value of university research as the difference between the total faculty salary bill and the (hypothetical) value of faculty as teachers only. This approach is based on the notion that faculty own certain teaching and researching skills, which earn a return in market. If a shadow price could be constructed which would reflect the hypothetical market of each faculty member as a teacher the difference between that figure and actual faculty salaries would reflect the return to research skills. Thus this approach is based not on a direct measure of output, but on the return to one of the inputs.

This proposal faces two major difficulties (not counting the practical difficulty involved in constructing the shadow price of teaching services). The use of faculty salaries as a proxy for research output presupposes that 1) the return to research productivity is pecuniary in nature, and 2) that a well behaved market for academic talent exists. If, as is possible, the return to an individual faculty member's research productivity accrues in the form of lower teaching loads, preferred teaching assignments, higher personal prestige, or the ability to work at a higher prestige university, any attempt to infer research productivity from faculty salaries will not work. In addition, there is no evidence to suggest that the market for academic talent in Ontario conforms to the conditions necessary for salaries to represent marginal productivity. On the contrary it is often the case that once a faculty member is hired, subsequent salary adjustments bear little relationship to further changes in marginal research productivity. Further, there does not appear to be the free mobility of established faculty members among universities which would be necessary to ensure that salaries reflect marginal productivity.(1) These observations suggest that in the case of university faculty members in Ontario, shadow prices for research productivity, no matter how well constructed, would be a poor proxy for actual research output.

A second approach which has been used in economic studies of university production is, like the first approach, based on an input measure. It has been suggested that the value of research output could be measured by the amount of faculty time spent 'doing research'. For example, Davies and Verry (1975) used faculty time logs to calculate the amount of time faculty members spent on each of the following tasks; teaching, research, and administration (they also allowed for unallocatable time). From these data they estimated cost and production functions for individual departments across universities in the U. K. in which the amount of faculty time spent researching (calculated from the faculty log books) was used as a proxy for research output. The argument that is made for this approach is that it is the activity of doing research which is the true output of universities and thus using an input measure is appropriate. Further, in a study that is primarily concerned with production and costs the appropriate measure of output to use is that which is directly related to the resources (in this case, faculty time) consumed. For example, in a study of the costs of oil exploration the proper measure of output would be wells dug, not oil found. The objection to this approach is that the use of an input as a

(1) For a discussion of these issues see: Scarfe and Sheffield (1977).

proxy for output assumes away production. Implicit in a study which uses this input based approach to measure research activity is the notion that research is not produced at a university but rather it is purchased, and its opportunity cost is the faculty time which could have been spent producing the teaching output.

A third approach to the measurement of research activity is to use the value of research grants obtained by individual faculty members or departments as the appropriate proxy for the research output. This is the approach taken by the Bovey Commission on the Future Development of the Universities of Ontario (1984). This approach would be very appealing if it could be imagined that universities, in obtaining research grants, are just pre-selling their research output. Viewed in this manner, research grants can be thought of as an output measure.

There are two objections to this approach. The first is that no matter how appealing the notion of pre-selling research may be, grants are really an input into the production of research, not an output. Thus all the objections which have been made against using an input measure as a proxy apply here as well. The second objection is that no matter what unit of analysis is chosen, it is impossible to standardize this measure across all the elements in the study. If grants are used to compare research across universities, as was done by the Bovey Commission, the result will be overvaluation of the research activity at universities with relatively larger departments in those disiplines which attract and require grants. A university that performs a great deal of medical research will, for example, appear to have greater research output than one that specializes in english literature. In fact, grants simply cannot be used to compare research output at the two universities. Even if grants are used to measure research across universities but only within one department (say physics), the measure cannot control for the differences in the types of research which might be pursued at different universities. Finally, it may be that grants are granted on the basis of criteria other than the actual value of expected research output. Grants may be allocated on the basis of departmental or university prestige or even on the basis of previous grant history.

Finally, the last approach to measuring research output which will be discussed here (and the one which will be used in this study) involves constructing an output proxy based either on patents or on publications generated by the research activity. While patents have been used as a measure of industrial or commercial research (Hausman, Hall, and Griliches, 1984) work on academic research has focused on publications in scholarly journals.(1) Implicit in this approach is the notion that academic research is publication directed (just as using patents implies that commercial research is patent directed). In either case the validity of the measure depends critically on the degree to

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(1) There is a vast literature on publications and citations by academics, especially economists. See Davis and Papanek (1984), Bell and Seater (1978), Graves et al. (1982), House and Yeager (1978). The most comprehensive and sophisticated analysis of journal importance in Economics, using citations, is Liebowitz and Palmer (1983, 1984).

which the underlying assumption is accurate. In the case of academic research, if research activity is not in any way directed to publications the use of publication data to proxy research activity is totally invalid. On the other hand, if the objective of all reseach in universities is to generate publications then publication data represent a true output measure, especially if quality-of-publication indices could be constructed using either institutional affiliations of authors (Moore, 1972, 1973), journal recognition amongst academics (Hawkins, Ritter, and Walter, 1973), or citations (Bush, Hamelman, and Staaf, 1974; Grubel, 1981; Liebowitz and Palmer, 1983, 1984). While it is probably true to say the the sole objective of all research is not simply publication, and it is certainly true to say that no true quality-of-publication index could ever be constructed, nonetheless this approach has the advantage that the measure is a physical output measure and as such is much more appropriate for use in a production study than would be an input based proxy.

2.5 Other Outputs

While teaching and research are the two major outputs of university production, it may be argued that there are other outputs which are produced by universities. As noted in Chapter 1, the Ontario Council on University Affairs has identified the provision of public service as one of the goals of universities in Ontario (OCUA, 1974). If it is a goal of the universities to provide public service, should it not be regarded as a third output? While there is no question that universities do provide public service in many ways, and this provides one of the justifications for the public funding of universities, it is not clear that the public service provided constitutes an output of the production process. In terms of modeling the production process, the outputs of any production process are what the firm intends to produce. Any other goods or services that are generated, provided that they have no market value and no disposal cost, are totally irrelevant from the point of view of modeling the production process. Instead, such goods or services should be regarded as external benefits or costs. The public service generated by universities should be regarded in this light. Universities produce teaching and research services and are funded on that basis. In the process of producing these outputs, public services are generated. However these public services are in the nature of a positive externality rather than a produced output and should not be explicitly included in a positive model of university production, although they are important in terms of determining the optimal level of public support for the university sector.

2.6 Inputs

The previous sections of this chapter have focused on the outputs of university production. This section will look at the other side of the production process, the inputs. Clearly a great many individual inputs go into the production of university outputs. However, for the purposes of analysis they can divided into four types: faculty time and productive human capital, student time and productive human capital, physical plant and equipment, and non-teaching personnel. Each will be discussed in turn.

It would appear that measuring faculty time as an input into the production process would be, conceptually at least, a simple procedure. In fact, depending on the measure of output used, defining faculty input into the production of that output can be problematic. As discussed above, universities produce more than one output. If the production process for each output is strictly separable then all variable factors of production could be assigned to one of the produced outputs. In this case faculty time could be divided into that proportion of faculty time which is spent on the production of teaching services and that proportion of faculty time which is spent on the production of research. On the other hand, if the outputs of universities are jointly produced in fixed proportions, as in the classic mutton and wool example, all inputs are inputs into both outputs jointly and the input measure would simply be faculty time spent producing the joint good. Unfortunately, the role of the input of faculty time into the production of the two university outputs, teaching and research, is neither a case of strict separability nor of fixed proportions. For example, time spent by faculty giving lectures is clearly an input into the output of teaching but it is not so clearly an input into the output of research. On the other hand it is quite likely that time spent preparing lectures could be considered an input into both teaching and research in many cases. As well, time devoted to research activities may or may not be considered an input into the production of teaching. In some departments it would seem that the two products are indeed produced separately and that time spent on the production of one is time which cannot be used for the production of the other. In other departments the joint relationship between teaching and research is strong and obvious. In many sciences, particularly laboratory sciences, graduate teaching and research are firmly linked, with departments accepting students not only into a program but also onto a research project.

The problem is what degree of jointness exists in the production of research and teaching, and to the extent that some faculty time is directed to one activity only, can faculty time be sucessfully allocated to the two activities? Any study into the economics of university production must come to grips with this problem, either explicitly or implicitly, and most researchers who have dealt with this problem have taken one of two approaches to it (excluding those who ignore the research output altogether and thus implicitly treat it as an intermediate good in the production of teaching).

One approach is to assume that some degree of separability exists, and to make an attempt to allocate faculty time into two categories; 'time spent researching' and 'time spent teaching'. This can be accomplished either by faculty time log books (Very and Davies, 1974) or by assumption (Bowen, 1980). The second approach is to assume faculty time is a homogeneous input which jointly produces both outputs, teaching and research, not necessarily in fixed proportions (Carlson, 1972). The first of these approaches has the advantage that the assumption of separabiliy allows the calculation of average and marginal costs and marginal physical productivities of inputs. This is an important consideration since it is these marginal and average costs which are so important in the debate over optimal tuition levels. The second approach would allow for marginal costs to be calculated, although it would not be possible to allocate fixed costs to individual outputs. However, in this case the marginal cost of producing any given output would depend, in part, on the quantity of the other output which is being produced. This is not the case if all outputs are produced separately.

Another difficulty regarding the measurement of the input 'faculty time' that must be dealt with is the fact that, in reality, faculty time is not a homogeneous input. No one would argue that all university faculty members are equally productive, especially in the production of research. This is because faculty are not homogeneous but rather each individual faculty member has a certain amount of human capital, and this human capital varies widely across individuals. This is not so important if the assumption of separability is maintained and only the teaching output is of concern, since it can be argued that all faculty are equally productive in terms of teaching output (especially if teaching output is measured in terms of a student-based measure). If, however, the study assumes joint production or focuses on the production of research it is necessary to attempt to measure the human capital embodied in individual faculty members. While this is a daunting task there are several approaches which might be employed. The research producing human capital embodied in individual faculty members might be proxied by the faculty member's degree attainment. While this approach might well work for some types of human capital it seems ill-suited for this particular case. Almost all individuals in the study will prove to have earned a Ph.D. (or equivalent). Those who have not will typically be the most junior and senior faculty members, who lack the doctoral degree for different reasons. An alternative approach might be to regard the experience of the faculty member as a proxy for research producing human capital. However, casual empiricism suggests, and various studies confirm that the age of individual faculty members is a poor predictor of research productivity (See for example; Grubel, 1981). One measure which does correlate well with research productivity is rank. This makes good sense since academic promotion is usually awarded on the basis of scholarly research, although criteria vary between departments. However, academic promotion is a reward for past publication. The extent to which rank is a good predictor of future research output really depends on the relationship between past research and promotion and past research and existing human capital. Thus the approach which this study will take is to proxy the existing stock of human capital by a measure of previous research output (which, as discussed above, will be based on scholarly publications).

The second type of input in the university production process is student time. As in the case of faculty time, difficulties arise over the role of student time in the production of the two different outputs. Clearly student time is a primary input into the production of the teaching output but, to the extent that jointness of production exists, student time may also play a role in the production of research. This possibility is particularly likely when the input is graduate student time. As well, like faculty time, student time is far from a homogeneous input. Like faculty, students bring different amounts of human capital to the production process. This problem is particularly important in the case where cognitive measures are used to measure the output of university teaching. Lemennicer (1977) argues that in this case ". . . the students are the direct producers of human capital through their own resources and particularly through study time. The academic staff affects student behaviour only indirecly through final examinations, teaching or research time and institutional characteristics". However if the teaching output is measured by a student-based measure (as is the case in this study) the difficulties involved in measurement of student inputs no longer exist by assumption.

Neither of the two other categories of inputs suffer from the conceptual difficulties in definition and measurement that plague those categories already discussed. Ancillary staff can be simply defined as all non-teaching personnel, and physical plant and equipment consists of the buildings, computers, library holdings, laboratory equipment, etc. that are owned by the university. However, the usual difficulties in allocating fixed inputs to individual outputs which exist for any joint production process still exist here.

2.7 Summary

In this chapter the conceptual and operational difficulties of defining the inputs and outputs of university production were examined. It was found that, while no single set of definitions is without problems, certain approaches are quite reasonable for the problem at hand. Specifically, the use of student-based data to measure the teaching output is quite acceptable as long as it can be assumed that the actual value of the measure (say, degrees granted) is constant across all units in the study. Further, the use of scholarly publications as a measure of research output, while more problematic, is preferable to the other approaches which have been used (such as time spent researching or faculty salary differentials).

Possibly the most difficult measurement problem exists with the definition and measurement of research-producing human capital. Since the degree attainment and experience of faculty are not a good measure it is necessary to rely on evidence of past research as an indication of current potential. Of the two measures suggested, salaries and past publication record, the latter is preferable.

This chapter began with a quote from Donald Bear (1974) which described the crucial problems in modeling the university's production process as consisting of the measurement and valuation of inputs and outputs, the specification of production relations and the issue of decision rules. In Chapter 3 the nature of those decision rules and their assignment within the university will be discussed and an economic model of university behaviour will be posited. In Chapter 4 the production relationship to be estimated will be specified.

CHAPTER 3

AN ECONOMIC MODEL OF UNIVERSITY BEHAVIOUR

3.1 Introduction

Traditionally, micro-economic theory has focused its attentions on two institutions, the household and the firm, and developed economic models to explain and predict the behaviour of these institutions. However, an economic model can be developed for any institution or organization that engages in purposeful (rational) behaviour. Thus, in addition to consumer theory and theory of the firm as found in standard micro-economic texts, economic models have been developed to explain the behaviour of institutions as diverse as clubs (Buchanan, 1965), collective farms (Domar, 1960), trade-unions (Ashenfelter and Johnson, 1969) and crime (Becker, 1968). Over the past twenty five years there has been increasing interest, possibly spurred by the work of Theodore Schultz (1960, 1961, 1963), in the economics of education, including the economics of university behaviour. One of the goals of this work has been "to develop a counterpoint view of education analogous to the theory of the firm" (Carter, 1965, pp.482). The approach to modeling university behaviour that has been developed over this period is predicated on the view of the university as a utility maximizing non-profit organization (NPO).

While NPOs of the type that will be discussed here have existed for a long time in industrial societies, there was little existing theoretical literature from which researchers interested in the economics of university behaviour could work. Instead, it appears that, during the last twenty-five years, the literature has been developed by researchers working on three different problems: The economics of hospitals, the economics of universities, and the economics of (publicly funded) Arts.

Baumol and Bowen (1965, pp. 497) define NPOs "as a group [which] share at least two characteristics: (1) they earn no pecuniary return on invested capital and (2) they claim to fulfil some social purpose". Baumol and Bowen might also have added that government financial support for NPOs has, over time, come to represent a very substantial proportion of public expenditure. This is particularly true in Canada as the functions of education, culture, and health care have moved out of the private sector and into the public sector. Since NPOs lack a profit motive to direct their activities, and since they they do appear to behave purposefully, it is necessary to hypothesize some other goal (in economic terms, an objective function) that such organizations seek to achieve. The most logical alternative to profit maximization as an objective is utility maximization. "The reason for choosing a utility maximizing model is two-fold. First, it enables one to insert into the appropriate utility functions entities that seem <u>a priori</u> to be plausible or appropriate in any given circumstance in which the model is to be used. Second, because it enables the use of economic hypotheses based on utility maximizing" (Culyer, 1970, pp. 352).

In a utility maximizing model there are three major questions to be answered: 1) Who are the optimizing agents, 2) subject to what constraints do they optimize, and 3) what entities enter into their objective functions? These three questions will be discussed below.

It is interesting to reflect that in developing an economic model of most industries the problem of identifying the optimizing agents within individual firms is usually not addressed. The firm is usually regarded as a monolithic whole without any concern for the within-firm distribution of decision making power since for most purposes this is an acceptable simplification. Yet in the case of NPOs this question is one of key importance. In almost all cases there are, within the NPO, two distinct optimizing agents; the administration and the producing unit. It is the administrators or administrative bodies that make decisions on staffing, on expenditures, often on outputs and on matters relating to the outside world (especially the funding agencies). However it is the producing units, who may be individuals or departments, who decide which technology is to be employed, and whose decisions determine the relationship between inputs and the quality and quantity of outputs. Thus, for example, in the case of hospitals, administrators may determine the number of beds, the number of doctors who have privileges, the number of nurses who are available on each ward, the admitting procedures for patients, and so on. But doctors determine the treatment that each patient is to receive. "The hospital is special . . . because it is actually two firms in one. There is one part run by doctors and another run by hospital administrators. . . The net result is one organization split into two disjoint pieces, each with its own objectives, managers, pricing strategy, and constraints."

(Harris, 1978, pp. 468-469) In universities, the split is between administrators who set admission limits, determine faculty levels in each department, and allocate internal resources for library acquisitions, computers, and physical plant; and faculty who determine what is taught, how it is taught and what research is performed.

The second question concerns the constraints under which the optimizing agents make their decisions. In general the constraints facing any agent are those characterizing the market in which the agent operates. In the case of NPOs the administrator is constrained by the demand for his output, both from the government funding agency and the public, the supply of inputs, and the production technologies chosen by producing units. The producing units are constrained by the decisions of the administrator, and how those decisions are affected by the behaviour of the producing unit, as well as the production possibilities available to the producing unit. Applying this to the case of Ontario's universities, the administrators are constrained by the funding formula, the availability of research grants, the demand for university education by students at various levels, the (government set) tuition rate, and the sources of other revenue. These factors make up the demand for the universities's output. In addition, university administrators are constrained by supply of qualified faculty and the market for other inputs. Finally, the university is constrained by the relationship between the quantity and quality of teaching output and research output and the quantity and quality of inputs which is given by each department's chosen production technology.

The university department can be modeled in one of two ways, depending on the context of the study. On one hand the department can be regarded as the primary producing agent which, operating very much like a labour cooperative (see for example; James and Neuberger, 1978), maximizes collective utility subject to the number and quality of faculty available to it, the number of students wishing to take courses at various levels, the physical and personnel support available, the ability of the department to influence any of the above constraints over time, and the range of technical possibilities available for transforming inputs into outputs. On the other hand the department may be regarded as a type of 'industrial park' in which the producing agents (which in this case would be the individual faculty members themselves) are brought together to produce output (research) subject to the constraints imposed by the characteristics of the department in which they operate, their own characteristics, and the technical relationship between these two types of characteristics and the production of the output (research). The personal characteristics of the individual faculty which constitute a constraint can simply be described as the faculty member's research producing human capital while the characteristics of the department would include the number and quality of other faculty members working in the same department, the ratio of students to faculty in the department, and the physical and staff support provided by the department.

The final question to be addressed is that of the utility functions themselves. Some early work (see for example Newhouse, 1970;

Feldstein, 1971; Bowen and Baumol, 1965) focused on the importance of the quantity and particularly the quality of outputs as the principle arguments in the utility functions of all optimizing agents. However, as Culyer (1965) points out, the quality of output will be far more important to the producing units whose own reputations are involved, than to the administration who are only indirectly affected by the reputation of the institution at which they work. As well, as James (1978) suggests, the producing units may get utility from the technology of production itself (i.e., professors may prefer small-class technology) while it is unlikly that admimistrators will have preferences with respect to technology. Another possibility is that administrators may get utility from the quality of inputs as well as the quality of outputs (Lee, 1975). In other words administrators may get utility from a new building or computer facility irrespective of that input's value in production. All of these proposed formulations are specific cases of a model that assumes the principle determinant of utility at both the administrative and producing unit levels is the institutional prestige where prestige is a function of the quality and quantity of both inputs and outputs, and where no presumption is made that the form of the utility function with respect to the elements of prestige will be the same for both administrators and producing units.

3.2 Modeling University Production

In the previous section universities were modeled as utility maximizing NPOs in which the university administration maximizes its utility function subject to the relevant constraints and, at the same time, the producing units (either the faculty or the departments) would maximize their individual (or in the case of the department, collective) utility functions subject to the relevant constraints. In this section the problems involved in specifying and estimating tractable production relations in such a model will be examined.

In a profit maximizing model "there are two general approaches to the specification of production technologies. One starts with the specification of a production function, and from this derives the implied dual profit, cost, and revenue functions. The second approach starts with the specification of profit, cost, or revenue functions whose partial derivitives generate a system of output supply or input demand functions." (Hasenkamp, 1976). However, in a model in which the optimizing agent is utility maximizing, instead of profit maximizing, great care must be taken in choosing the form which the estimation procedure will take.

Most empirical work which attempts to estimate production processes assumes that one output is produced by several inputs through the application of some production technology. However, as explained in Chapter 2, universities produce two outputs and thus the simple one output, multi-input production function cannot accurately describe a university's production process. Instead, a multi-output multi-input transformation function and/or its dual, the multi-product cost function must be employed. The duality which exists between transformation functions and cost functions ensures that all the information about production technologies that is contained in one is equally contained in the other (Hall, 1973). However, a number of considerations enter into the determination of which approach (that of specifing a cost function or that of specifying a transformation function) is best employed.

A transformation function, written as $T(X,Y,Z)=0$ where X and Y are outputs and Z is a vector of inputs, defines the outer boundary of the set of feasible production possibilities. Written as an equality it presumes that production takes place on the transformation surface and not at an interior point. This means that if technical efficiency is assumed, and if it is assumed that all units under study face the same set of production possibilities, then all data points observed will deviate from the transformation surface only by the amount of the random disturbances which occur in the generation of the data. Technical efficiency in production is assured if the economic agents generating the data (firms) are either profit maximizers, revenue maximizers (with a profit or loss constraint), or cost minimizers. It will also be the case when the firm is a utility maximizer provided two conditions are met. The first is that the firm get positive utility from all outputs or, if the firm gets no utility from an output, that its price be positive. Under either of these situations the firm has no incentive to produce inefficiently. However if the firm gets negative utility from an output, even if that output has a positive price the firm will not, in general, produce on the transformation surface. The second condition is that the outputs must be endogenously determined by the firm. If the level of outputs is exogenously determined and the firm is left to choose input levels and production techniques to maximize utility, efficient production may not result. These two points are illustrated with the help of the diagram given in Figure 1.

Figure 1

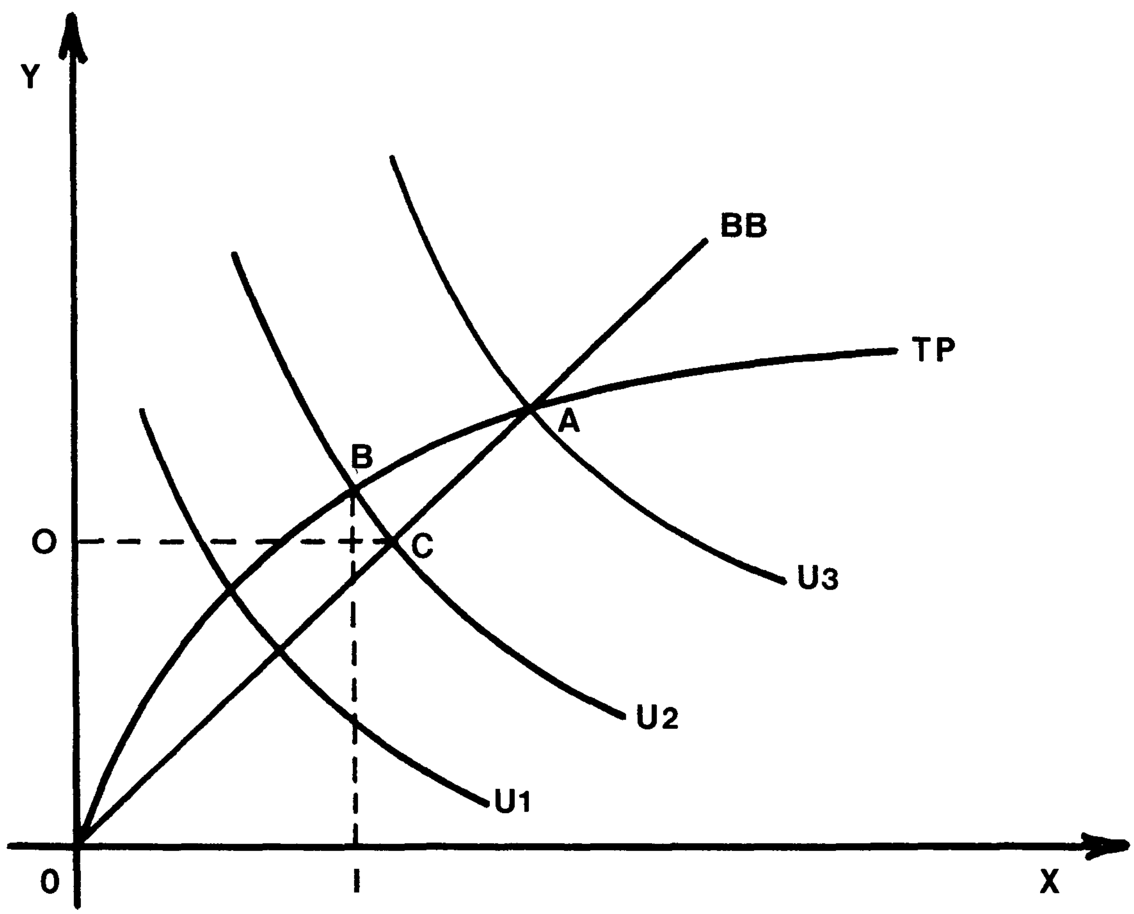

Figure 1 shows the situation for a simplified model in which a firm maximizes a utility function which is a positive function of one output (Y) and one input (X) subject to the constraint that output is some function of input (ie: subject to the transformation function) and the constraint that the output price (P) times output minus input price

(R) times input must be non-negative.(1) The lines U1, U2, and U3 represent indifference curves where total utility rises as the curves move further away from the origin along a ray. The TP line represents the transformation locus T(Y,X)=0 with points above the line being unattainable and points below the line being attainable but technically inefficient. Finally the BB line represents the balanced budget line with points above the line representing points of positive profit. The slope of the BB line is R/P. The slope of the TP line is the marginal physical product of input in the production of output, and the slope of the indifference curves is the rate at which the firm is willing to trade input for output and still retain the same total utility (i.e., the MRS of X for Y). If the firm can determine both the level of input and the level of output endogenously given R, P, and the transformation curve TP, it will maximize utility at point A where utility attains the greatest possible level given the constraint that profit must not be negative. If input was fixed at some exogenously determined level (say I) the firm would choose to produce at point B as no point above B is technically possible and no point below B yields as much utility. Both point A and point B are on the transformation surface. However if output were fixed at some exogenously determined level (say O) the firm would maximize utility by operating at point C, within the

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(1) This particular problem has considerable relevance here, since university departments may well get utility out of inputs. It has been argued (Lee et al., 1975; James, 1978) that university departments get utility out of the number and quality of faculty inputs, irrespective of their value in production.

transformation boundary. There are two further points to note about Figure 1. The first is that if output is the only argument in the firm's utility function and if it is a positive argument the firm will always operate on the frontier. However this is an uninteresting case of utility maximization since in the one output case it is equivalent to revenue maximization and in the multi-output case it is equivalent to revenue maximization using shadow prices instead of market prices. The second point is that if the firm gets positive utility from inputs but negative utility from outputs it will never operate on the frontier except by chance (operating instead where MRS = R/P).

If the process by which university outputs are produced is going to be modeled and estimated using either the transformation function or the cost function approach the following questions will have to be considered. (1) What is the appropriate unit of analysis, (2) what is the appropriate time frame for the analysis, (3) what is the general form of the utility function whose maximization generates the data, and (4) which variables are endogenous and which varables are exogenous to the optimizing agent?

The first question to be dealt with here concerns the issue of which variables are exogenous, which are endogenous, and which are choice variables from the point of view of the university department. If the study is based on a short-run (one academic year) model, many of the variables which enter into the utility function and constraints of the department are exogenous to the department. On the input side, both the number of faculty and their characteristics, such as vintage and embodied human capital, are fixed. This is in contrast with the firm of standard microeconomic theory for which labour input is presumed to be a short-run choice variable. In the case of the university department, almost all inputs can be considered fixed in the short-run (i.e., one academic year). On the output side the teaching output may be considered fixed or variable, depending on the operational definition of teaching output used. While the amount of human capital value added to students is clearly endogenous, will depend on the department's production decisions, and will react to changes in inputs or production techniques, neither student enrolment nor degrees granted will depend on the production process. They can be considered exogenous in the short-run. On the other hand, research output, measured by any of the proxies discussed, is endogenous. Whether research is measured by the number of publications generated, the number of research grants obtained, or even the total time spent researching it will be endogenously determined by the amounts of inputs and the production process used.

On the other hand if the study takes a longer view of university production many variables which are exogenous from the point of view of the department in the short-run can be considered to be endogenous, although not choice variables, in a long-run model. For example, student enrolment or degrees granted will, in the long-run, be endogenously determined jointly by departmental decisions on course content, academic standards, and degree requirements, and the preferences of students towards an education in any given field. As well, university decisions, the actions of other departments, and a host of demographic and social factors will determine enrolment in any one department. It is also the case that the total number of faculty employed as well as all other inputs will, in the long-run, be determined by departmental actions, administration preferences, the availability of research funds from outside agencies, student enrolment, etc. Therefore in a long-run model of departmental production these variables should be taken neither as fixed, nor as choice variables whose levels may be set by the department but as endogenously determined by the actions of several agents, departments among them.

Since it was argued in a previous section that university faculty members, either individually or collectively, are the producing units, they are the relevant units of analysis for a production study. The university as a whole (i.e., the central administration) would be an inappropriate unit of analysis since in no real sense does the central administration make production decisions. Rather it determines the constraints under which individual faculty and departments operate. The choice between using the individual faculty members and individual departments is crucial. In a long-run study, where it is assumed that both teaching and research outputs are endogenous, the approporiate unit of analysis would be the individual department since it cannot be argued that the 'industrial park' analogy works well here. If both research and teaching are considered to be the endogenous outcome of the production process it is the department whose decisions, subject to the constraints imposed by the university administration and by the abilities of faculty members, affect the production of those outputs.

On the other hand for a short- run study in which the teaching output is fixed exogenously at the begining of the production process and, therefore, the only endogenously produced outcome of the production process is research, individual faculty members are the appropriate unit of analysis.

For any production study to be possible it is necessary to assume that the production technology is constant across all elements in the study. If the unit of analysis is the university department then only by including departments within the same discipline can this assumption be maintained. If it is assumed that the technology of production is unchanged over a period of time then an analysis of one department's production decisions over time (a time-series analysis) is possible. On the other hand, if it is assumed that the technology of production is the same for all departments in the same discipline but only at one given period of time then an analysis of the production decisions of a number of departments during one academic year (a cross-sectional study) is indicated. As indicated above, it is inappropriate to consider the individual faculty members as the units of analysis in a study where the teaching output is endogenously determined, such as would be the case with a time series study. However, for a study based on cross-sectional analysis, in which the teaching output is assumed fixed, the set of elements for which a production study is possible would be all faculty members who work in departments in the same discipline.

From the above analysis it follows that only two approaches are possible. One is to assume that the production of teaching and research output in all departments is subject to the same production possibilities in any given year, in which case the time frame is one year and a cross-sectional study should be undertaken using either the department or the individual faculty member as the unit of analysis. The other is to assume that the production of outputs are subject to the same production possibilities over time, in which case a longer time frame should be used for a time-series analysis of production in an individual department. Of course if all departments in one subject face the same production possibilities over time then a pooled cross-section and time-series study is possible.(1)

If the unit of analysis is the individual department, then the theoretical literature on departmental objective functions suggests that a utility function in which both inputs and outputs enter positively is appropriate. For example, Garvin (1980) uses such a formulation and describes the function of inputs and outputs that enter into a

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(1) The terms short-run and long-run have been used here to refer to situations in which at least one input is fixed and situations in which all inputs are variable, respectively. It must, however, be recognized that all departments operate in the short-run and that even time-series data represent a series of one period optimization decisions. Further, cross-section data represent firms at different levels of inputs which reflect long-run optimization decisions. These are important considerations in a study which attempts to estimate cost functions, where differences exist between long and short-run cost curves. However in estimating a production function all observations are on the transformation surface in both the short and the long-run. Therefore, the issue of cross-section vs. time-series analysis relates only to the question of determining which variables are endogenous and which are exogenous.

department's utility function as the unitary measure 'prestige'. Culyer (1970) also suggests that departmental prestige will be the main aspect of departmental utility and that inputs will enter into the determination of prestige. Two inputs which will certainly enter into the utility function of departments through prestige are the number of faculty members employed (i.e., departments prefer to be large, cet. par.) and the human capital of departmental members (i.e., departments prefer faculty with ability for their own sake, over and above their value in production). A difficult question concerns whether departments get negative utility out of either of the outputs, teaching and research. While there is no doubt that departments get positive utility out of research there have been some suggestions that teaching, especially undergraduate teaching, should be regarded as a negative argument in the departmental utility function (James, 1978). While individual faculty members may prefer less teaching to more teaching, as seems likely, there is no reason to believe that an academic department as a whole does not receive positive utility both from the quantity and quality of student enrolment. Accordingly, the first condition for estimating transformation functions in utility maximizing models, that output be a positive argument in utility, is met in the case of university departments. In the case of individual faculty members these issues do not arise because all inputs and the level of teaching are fixed and thus as long as the individual faculty members are assumed to be research maximizers subject to the constraints imposed by the (fixed) levels of inputs a production study is possible.

3.3 Transformation Functions and Cost Functions

The final issue to be addressed is whether the production process should be estimated in the form of a transformation function or in the form of a cost function. This issue will will be dealt with in this section.

The major issue concerns the problem of dealing with the putative jointness in production between teaching and research. Jointness in production is the situation in which the marginal productivity of any input in the production of one output is a function of the level of the other output(s) produced. If the two outputs of university production are not jointly produced the transformation function $T(X,Y,Z)=0$ can be rewritten as $Y=F(X1)$ and $Z=G(X2)$ where $X1 + X2 = X$. In addition to the assumption of total separability, this approach requires that the total value of inputs (X) be separated into those inputs which are exclusively applied to the production of Y and those which are exclusively applied to the production of the second output, Z. If it is desired to specify a functional form that allows for the possibility of jointness in production there are two options available. The first is to estimate the transformation function directly as an implicit function of all inputs and outputs. This is the approach recommended by Vinod (1968, 1969, 1976) who suggests the canonical correlation analysis as an econometric technique to deal with this approach, although there do not appear to be any published instances of this technique being used for university production. Two studies which have attempted to estimate the implicit transformation function directly have both used an alternative statistical technique, that of fitting a convex polytope to the data (Carlson, 1963; Lindsay and Bailey, 1980).(1)

Another way the transformation function can be estimated which will still allow for the possibility of jointness is to estimate it indirectly. This can be accomplished by estimating one output (endogenously determined) as an explicit function of inputs and other outputs (exogenously determined). While this technique does not assume away jointness in production it does impose restrictions on the form that the underlying transformation function may take.

If a production approach is not adopted, duality theory suggests that the same information may be obtained from a cost function. Most of the empirical work on university production has followed this approach (see for example; Maynard, 1971; Brovender, 1974; Layard and Very, 1975; James, 1978; Bowen, 1980; Tierny, 1980; Brinkman, 1981). The major reason for the popularity of this approach is that the empirical results

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(1) Convex polytope analysis is a procedure for estimating the facets of the convex hull of observations in input-output space. It is predicated on the notion that since the transformation surface represents the maximum production possible from the given level of inputs, it is not possible for observations to lie outside the surface. The econometric technique which is based on the same notion is the production frontier analysis (see Forsund et al., 1980, for an analysis of this issue). However, OLS is a consistent estimator of the slope parameters of the production frontier (although not the intercept parameter) and thus unless the objective of the study is to compare relative efficiency of the elements under study, such as in Cavin and Stafford (1985), little is gained from this technique.

which are often of most interest are the marginal and average cost of teaching which are directly available from a cost function, while in order to obtain the same information from a production function input prices would have to be known or estimated.(1) In the case of joint production the average cost cannot be calculated in either case. Another reason for the popularity of cost studies may be the statistical difficulties involved in estimating joint production processes (in cases where jointness is assumed).

Whatever the reason for its popularity, the use of a cost function approach imposes severe restrictions on the underlying model. If the study assumes production technologies are not invariant over time a short-run cross-sectional study is appropriate. However, in order to estimate a cost function it is necessary to assume that the department is producing not only technically efficiently but also economically efficiently. In other words, it requires that the department be producing at least cost. This is assured if the department is a profit maximizer, revenue maximizer or cost minimizer. It is also assured if the department maximizes a utility function in which only outputs appear

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(1) A theoretical cost function is a function of output and factor prices. The derivative of this function, with respect to output, is the marginal cost of production, which is a function of output and factor prices. Thus, in order to determine a value for the marginal cost of production at any given level of output, it is necessary to know the values of factor prices. However, as explained below, the empirical cost studies discussed here have estimated cost as a function of output alone, and thus it is possible to derive an estimate of the marginal cost of production without knowing the values of factor prices.

as arguments. However, if the department maximizes a utility function in which both outputs and inputs appear as positive arguments, then least cost production is not assured and it is no longer appropriate to estimate a cost function. Thus while the theoretical literature suggests that university departments maximize a utility function in which inputs are important much empirical literature has been based on the contrary assumption.

Furthermore, it is only possible to derive production functions from estimated cost functions if the cost functions have been specified as functions of outputs and factor prices. In order to estimate such a cost function it is necessary to obtain data on factor prices. Because of the difficulties in calculating these data, existing cost studies have assumed that all departments face the same factor prices for all inputs, including human capital. This allows the cost function to be estimated as a function of output alone. However, this approach does not allow the production function to be derived from the resulting cost function. On the other hand, from an estimated production function, where output is specified as an function of inputs, it is possible to derive the corresponding cost fuction.

3.4 Summary

The university is modeled as a non-profit organization in which the university-wide level of production is determined by the decisions of two sets of agents, administration and faculty, each of whom maximize their own objective functions in which the quality and quantity of inputs and outputs may be presumed to enter. Output is produced by faculty members within departments and this process of production can be modeled and estimated using either transformation functions or cost functions, although cost functions are only appropriate for time-series studies under certain simplifying assumptions. A transformation function in which research output and teaching output are jointly produced may be estimated using longitudinal or pooled departmental data if the technology of production is invariant over time. If technology is not invariant over time a transformation function for the production of output using cross-sectional data either on departments within one discipline or on faculty within one discipline is appropriate. However if the measure of teaching output used is student-based, teaching output should be regarded as an exogenous variable and research output should be estimated as a function of inputs and the level of teaching output.

In the next chapter a cross-sectional model of university production will be posited and all variables will be objectively defined. In Chapter 5 the model will be estimated using data from departments of economics at Ontario's 15 universities. In Chapter 6 the results of the estimation will be used to examine various policy proposals, while in Chapter 7 the sensitivity of the results to various assumptions, data definitions, and data collection procedures will be examined.

CHAPTER 4

A STATISTICAL MODEL OF UNIVERSITY PRODUCTION

4.1 Introduction

In Chapters 2 and 3 some of the problems involved in modeling and estimating university production were discussed. As explained in those chapters, meaningful estimation depends crucially on the unit of analysis, the time frame, and the operational definitions of inputs and outputs. This chapter consists of three sections. The first section discusses the scope of the analysis, i.e., the unit of analysis, time frame and conceptual definitions of the variables. The second section presents the model which will be estimated in Chapter 5, and the third section gives the operational definitions and data sources of the variables used in the empirical analysis.

4.2 Scope of the Analysis

It was noted in Chapter 3 that the unit of analysis for most existing cost or production studies of universities has been either the university as a whole or, more commonly, the individual university department. However, it was also noted that under certain circumstances, the individual faculty member may be the most appropriate unit of analysis for a study of university production.

It is possible to view the relationship between faculty and department as analogous to the relationship between department and university. The department is the producing unit of the outputs, research and teaching, and it makes its production decisions subject to the constraints set by the university. In the same way it is possible to view the individual faculty member as the producing unit of the research output subject to the constraints imposed by the department. In other words, the individual faculty member is regarded as the producer of research who 'sells' that research producing capability to the university department. The research producing capability of the individual faculty member can be formalized as a production function which relates research produced to the human capital embodied in the faculty member, characteristics of the individual, and characteristics of the department, such as teaching load, level of teaching (i.e., undergraduate, masters or doctoral level), quality and quantity of other faculty, and so on. The department then takes this relationship as a constraint on its ability to produce research and teaching output. Thus the departmental transformation function discussed in Chapter 2, in which the level of outputs, teaching and research, are implicitly related to the levels of inputs, including number of faculty and human capital embodied therein, contains within it this production function for the research output of individual faculty. Note that this approach does not deny the possibility of joint production between teaching and research. The production function which relates the research output of the individual faculty member to the teaching output of the department in which he is employed may be specified so as to exhibit jointness in production.

In deciding on the appropriate approach to model and estimate the production process involved in university production, much depends on how the outputs, and particularly the teaching output, are defined. If the measure of teaching output used is a cognitive measure of the value added to the human capital of students taught, then this measure is endogenous to the department, even in the short-run, and the appropriate unit of analysis is the university department. On the other hand if the study uses a student-based measure, then the teaching output is really exogenous to the department in the short-run, and the only endogenous output is research output. In this case the teaching output can be regarded as an input into the production of the only endogeneous output, research.

This study will accept the convention of all other university production studies and use a student-based measure of the teaching output. The advantages of this approach are partly practical (i.e., only student-based data are available) and partly determined by the objectives of the study.(1) The study is concerned with evaluating approaches to improving efficiency in the production of university outputs, however they are valued. It is irrelevant from the point of view of this study what attributes are embedded in a university degree

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(1) All the studies of universty production discussed in Chapter 2 used student-based measures of the teaching output, either enrolment or degrees granted. Only Very and Davies (1974) attempted to incorporate the aspect of value-added into the definition of teaching output. They did this by using class of degree (i.e., first class honours, second class honours, etc.) as well as level of degree.

or what the social value of university research is. Since a student-based measurement approach is being adopted, either the university department or the individual university faculty member would be the appropriate unit of analysis. As explained in the next section, if the teaching output is assumed exogenous the two approaches are conceptually the same, although there are significant advantages to estimating a model based on the individual rather than the department as the unit of analysis. Since a student-based approach to the measurement of the teaching output is being adopted, the scope of the study must be chosen so that the attributes contained within the specific student-based measure used can be assumed constant. For that reason the scope is restricted to include only individual faculty members employed by departments within the same discipline (i.e., departments of economics or departments of political science). This is a logical restriction to make when using a student-based measure of teaching output. Indeed, it might even be argued that the restriction should be extended further and that only faculty within one specific department (say, the Department of Sociology at the University of Waterloo) should be included in the scope of analysis. This approach would imply that a degree in sociology earned at one university is so qualitatively different from one earned at another that faculty in different departments face different production possibilities and thus have different production functions. This approach will not be adopted here, and instead it will be assumed that all faculty working in departments of (say) sociology face the same production possibilities although they will, of course, face different constraints.

Finally, the scope of the analysis will be restricted to include the production of faculty members within a very restricted time frame. The reason for this restriction is that only within a restricted time frame can the teaching technology, even within the same discipline, be considered constant. For the purposes of estimating the model, the time frame will be restricted to the 1981-82 academic year.

4.3 The Model

In this study the (student-based) teaching output is assumed to be exogenously given to the department in the short-run. In any given year, the department attempts to produce as much research output as possible given the level of enrolment at various levels, the number of inputs which have been exogenously determined by the university, and the technical relationship between inputs and outputs that it faces. As discussed in Chapter 2 the department will choose to produce in a way that is technically, if not economically, efficient. Since the teaching output is exogenous to the department, it may be regarded as an input and placed on the right hand side of the equation. A production function for the production of research output in a given discipline across N universities could be written as:

$$\begin{aligned} AVRESj = f(&DEPHCj, AVBAj, AVMAj, AVPHDj, SIZEj, \\ &PCj, DCj) \end{aligned} \tag{4-1}$$

where: AVRESj : average (per faculty member) level of research output at university j

DEPHCj : average level of human capital at university j

AVBAj : enrolment at the bachelor's level per faculty member at universty j

AVMAj : enrolment at the master's level per faculty member at university j

AVPHDj : enrolment at the doctoral level per faculty member at university j

SIZEj : total number of faculty members employed at university j

PCj : a vector of average levels of personal characteristics of faculty members employed at university j

DCj : a vector of average levels of departmental characteristics of at university j

and j = 1 . . . N

Equation 4-1 presents the general form of a production function for the average (per faculty member) departmental production of research as a function of per faculty enrolment at various levels, the total number of faculty employed, the average levels of various relevant characteristics of employed faculty, notably human capital, and the average levels of various relevant departmental characteristics. For convenience, the subscripts will be ommitted in the discussion below.

The variables SIZE, DEPHC, PC, and DC are all inputs into the production process. Since the variable SIZE measures the total number of faculty members employed, it also implicitly appears in the denominator of all other right hand side variables, since they are expressed as per faculty averages. Thus if all inputs and all teaching outputs were changed by the same percentage, all RHS variables except SIZE would remain unchanged. Thus, if economies of scale existed over some range, so that an equal percentage increase in all inputs and teaching outputs would cause a greater percentage rise in total departmental research output, d(AVRES)/d(SIZE) would be positive over that range.(1) The optimal number of faculty members, cet. par., will be found where d(AVRES)/d(SIZE) = 0. As well, since equation 4-1 can be regarded as an implicit function for the production of the teaching output, a positive relationship between AVRES and SIZE would could also be interpreted to indicate economies of scale (as defined in the footnote below) in the production of all outputs.

In addition to SIZE, which is an indicator of economies of scale, it is expected that average research output will be a function of the average levels of inputs. DEPHC is the average level of research-producing human capital. Thus, d(AVRES)/d(DEPHC) is the marginal physical product of the human capital into the production of research and should be positive, at least over the range of observed values. The second derivative will indicate whether the marginal product of this input increases, decreases, or is constant as its level increases, cet. par. PC represents a vector of average personal characteristics which may influence average research output. As the discussion in Chapter 3 indicated, the standard approaches to measuring human capital tend to capture all of the personal characteristics, such

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(1) The usual definition of economies of scale is that they exist when an equal percentage increase in all inputs causes a greater percentage increase in the level of output. However, in the case of a multi-output production function, it makes more sense to make the definition in terms of an equal percentage increase in all inputs and all outputs but one. This is what has been done here.

as quality of education, intelligence, ambition, etc., which influence research productivity. It may, therefore, be impossible to obtain an efficient estimate of the role of these characteristics on research productivity, even in cases where the characteristics can be measured. Finally, DC represents a vector of relevant departmental inputs such as computer facilities, support staff, and equipment. As inputs, these variables would be expected to be positively related to research output.

The analysis of the variables representing teaching output (AVBA, AVMA, and AVPHD) is not so straightforward. The partial derivative d(AVRES)/d(AVBA) represents the change in the average level of departmental research for a marginal increase in the average (per faculty) level of students enrolled in Bachelor's programs. To the extent that faculty time and other resources spent providing teaching services cannot be used to produce research we would expect this marginal to be negative. The same analysis would apply to d(AVRES)/d(AVMA) and d(AVRES)/d(AVPHD). However, to the extent that graduate education, and particularly doctoral education, is jointly produced with research, this effect will be mitigated. For example, it may be that both the time spent preparing undergraduate lectures and the time spent giving them are lost to the production of research while the time spent preparing graduate lectures is also an input into research. This would tend to lower the magnitude of the negative coefficient on the terms AVMA and AVPHD, or to make these coefficients positive. In addition, it is possible that the existence of graduate students in a department and/or the necessity of teaching at the graduate level may enhance the application of human capital to research. In this case the partial d(AVRES)/d(DEPHC) should increase as AVPHD increases. A significantly positive sign on an interaction term between AVPHD and DEPHC would support this hypothesis.

One of the major difficulties with estimating Equation 4-1 would be that while the department, through its decisions on teaching loads and so on, determines the constraints under which individual faculty members produce research, it the faculty members themselves and not the department that do the producing. Therefore, much of the determination of actual research output will rest with characteristics of the faculty members themselves, particularly the human capital of the individual faculty member concerned. If equation 4-1 were to be estimated directly, the relationship between research output and the characteristics of the faculty would either be ignored or obscured through the aggregation process. For example, it may be that the production of research by any one individual would be affected not only by his or her own human capital but also by the human capital of other members of the department. However the term d(AVRES)/d(DEPHC) derived from equation 4-1 above would aggregate these two effects. Additionally, the within department distribution of human capital may be important in that departments with a highly unequal distribution of human capital may be more (or) less productive than those with less a less unequal distribution of human capital, holding average levels constant. This effect could be accounted for by employing higher moments of the distribution of human capital as independent variables, although this procedure may prove troublesome in cases where degrees of freedom are limited.

It is for these reasons that instead of choosing the department as the relevant unit of analysis and estimating equation 4-1 directly, the individual faculty member is chosen as the unit of analysis. Instead of the departmental production function given in equation 4-1 the equation which is estimated represents a production function of research output by the ith faculty member at the jth university in a given discipline. The production function is given as equation 4-2 below:

$$RESij = g(HCij, DEPHCj, SIZEj, AVBAj, AVMAj, AVPHDj, PCij, DCj) \qquad (4\text{-}2)$$

where: RESij : total research output of faculty member i at university j

HCij : the human capital of faculty member i at university j

PCij : a vector of personal characteristics of faculty member i at university j

AVBAj, AVMAj, AVPHDj, SIZEj, DEPHCj, and DCj represent the bachelor's, master's and doctoral level enrolment per faculty, total number of faculty members, average departmental human capital, and a vector of departmental characteristics, as before.

Although the equation which will be estimated represents the production function for an individual faculty member's research output, it is possible to interpret the estimated coefficients as coefficients of a departmental production function. This can be demonstrated quite simply as follows. For simplicity assume the RHS of the estimating equation includes variables which are the same for all members of the same department (such as DEPHCj or AVPHDj), variables which are different for all individuals (such as HCij), these terms taken to a higher power, and intereactions between these terms. This represents a total of five possible types of variables (although in the actual regressions some types may be absent for theoretical or statistical reasons). The five types can be represented as departmental variables (DV), individual variables (IV), both types taken to higher powers (DV2, IV2) and interactions between departmental variables and individual variables (DV*IV).(1) Assuming an essentially linear form, the estimated equation is represented as:

$$RESij = a + b1(DVj) + b3(IVij) + b3(DV2j) + b4(IV2ij) + b5(DVj*IVij) \quad (4\text{-}3)$$

The estimated values of b1, b2, b3, b4, and b5 relate changes in the independent variables to the resulting change in the research output of any one individual faculty member. Thus, for example, d(RESij)/d(DVj) = b1 + 2b3(DVj) + b5(IVij).(2) To transform equation

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(1) Interactions between different departmental variables or between different individual variables will have the same aggregation properties as departmental or individual variables taken to higher powers.

(2) For simplicity, it is assumed that there is only one departmental and one individual variable, and that the only terms to higher powers are squared terms. The generality of the discussion is not impaired by this assumption.

4-3 into one for average departmental production of research, both sides should be summed over i within each department and then divided by SIZEj. The left-hand side would become $\sum_i$RESij/SIZEj which is equal to AVRESj, the average research output of the jth department, and the left-hand side variable in equation 4-1. On the right-hand side of the aggregated equation 4-3, the constant will remain unchanged, since it is being summed over SIZEj and then divided by SIZEj. Similarly the second and fourth terms, b1(DVj) and b3(DV2j) will remain unchanged since departmental variables are constant for all individuals in the department at one university. The term b2(IVj) will, on aggregation, become b2($\sum_i$IVij/SIZEj) which is the average level of the individual variable in the department at university j. The term b5(DVj*IVij) will, since DVj is constant over i within each university, become b5(DVj)($\sum_i$IVij/SIZEj). Thus, since all departmental variables are already expressed as per faculty averages, the coefficient b5 in equation 4-3 can be interpreted in terms of a departmental production function as the coefficent on the interaction between average (per faculty) departmental and individual characteristics. Finally, the term b4(IV2ij), when aggregated, will become b4($\sum_i$IV2ij/SIZEj). Note that this is not the square of average personal characteristics, but the average of squared personal characteristics and thus coefficients on higher powers of individual variables (such as HCij) should be interpreted as coefficients on the moments of the within university distribution of the personal characteristic.(1) Thus equation 4-3 would become:

$$AVRESj = a + b1(DVj) + b2(\sum_i IVij/SIZEj) + b3(DV2j) + b4(\sum_i IV2ij/SIZEj) + b5(DVj)(\sum_i IVij/SIZEj) \qquad (4\text{-}4)$$

For this reason the interpretation of equation 4-2 is similar to that of equation 4-1. The sign of the derivative of RESij with respect to AVBAj should be negative, as AVBAj represents the other output and an increase in one output should cause a fall in the other, holding inputs constant. It is not as clear, a priori, what sign should be expected for the derivative of RESij with respect to AVMAj and AVPHDj. A positive sign would suggest that research and graduate teaching are jointly produced to such a degree that the latter is an input into the production of the former. Even if the first derivatives are negative, the signs of the appropriate cross partials might still reveal the existence of joint production. In any case, the derivatives of RESij with respect to any of these variable can be interpreted as the effect of a change in average departmental enrolment on the average departmental research output.

The variable HCij is an input and thus d(RESij)/d(HCij) should be positive and would be interpreted as the increase in any individual's research output resulting from a marginal increase in that individual's

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(1) Note that when interpreting the individual production function as one for average departmental production personal variables, such as HCij, taken to the power n, should be interpreted as the sample nth moment around zero.

human capital. The marginal d(RESij)/d(DEPHCij) will take on a positive value if one individual's research output is positively related to the average human capital of the department. The expression d(RESij)/d(SIZEj) describes the effect on any one individual's research output for a marginal increase in the number of faculty members in the department, holding all departmental averages (such as AVPHDj or DEPHCij) and the absolute levels of personal characteristics (such as HCij) constant. However, since equation 4-2 can also be interpreted as a departmental production function in which all right-hand side variables (departmental, personal, and interaction terms alike) except SIZEj are expressed as per faculty averages, d(AVRESij)/d(SIZEj) will indicate the existence of returns to scale.

In equation 4-2 PCij represents a vector of personal characteristics which might be important in explaining the variation in research output across faculty members. The most obvious one (pursuing the analogy between physical and human capital) might be the vintage of existing human capital. This could be measured in various ways. For example one measure of vintage might be years at present institution or years since first publication. As well, academic rank may be important in determining the relationship between RESij and other variables. A dummy variable might be included for faculty with administrative responsibilities.

4.4 Objective Definitions of the Variables

As described above, the unit of analysis for the study is the individual faculty member and the scope of analysis is restricted to all faculty members employed in a department in a given discipline for the academic year 1981-82 in Ontario. Therefore, for the primary discipline under study (economics), a master data file was created in which there was one observation (on each variable) for each faculty member.(1) Regression analysis was used to estimate the production function. The master file consisted of observations on 17 variables for each of the faculty members who were employed in 1981-82. These 17 original variables were then transformed to create further variables (such as squared or interactive terms) which could be used in the regressions.

The list of all faculty members in departments of economics was compiled from information in the Commonwealth Universities Yearbook (CUY) and in the university calendars of each of the 15 universities. It was recognized that slight inaccuracies might exist in these lists due to the lead time required for publication. However this presents a problem only to the extent that lead time differed between universities. There is no reason to believe that a significant measurement problem exists with these data. These same two sources were used to gather observations on 3 of the 17 original variables. For each faculty member a variable UNIVj was created in which the university of employment (01=Brock, 02=Carleton, 03=Guelph, etc.) was recorded. This information

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(1) The data collection procedures described here were also carried out for two other disciplines, political science and sociology. A comparison of the results for the three disciplines is performed in Chapter 7.

was used to create university specific dummy variables. SIZEj recorded the number of faculty members employed in the department where the individual worked and took on 15 different values, the sum of which equaled the total number of observations in the file. Finally, the variable RANKj contained a number corresponding to one of four academic ranks (1=Full Professor, 2=Associate Professor, 3=Assistant Professor, and 4=rank below Assistant Professor). Again, these were used to create dummy variables.

The second source of data was the Social Science Citation Index (SSCI). The SSCI's source index gives an alphabetical list of all individuals who, in a given year, publish something (i.e., an article, note, book review, etc.) in one of a substantial list of scholarly journals, along with a certain amount of information about the item(s) published.(1) As such it has become a standard source of information on the research output of individuals, departments, and universities. Therefore it was possible to create a separate publications file on each individual who was listed on the master data file. The publications file listed the number of publications by year and recorded as well the type of publication, the number of authors, and the journal in which the publication appeared. In addition, it is possible to calculate the length (in non-standardized pages) of the article. This aspect of the

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(1) The SSCI attempts to survey as wide as possible a list of English language scholarly journals in the Social Sciences as well as a number of foreign language journals. The list of journals surveyed increases every year, however for the 1976-1982 period the list contained over 5500 journals.

data was used to test the sensitivity of the results to various objective definitions of the research output (the results are presented in Chapter 7).

From the data in the publications file seven more variables were created. These seven variables consisted of the total number of publications, excluding book reviews and minutes of meetings but not weighted in any other way, in each of the seven years from 1976 to 1982 inclusive. These variables were named D76, D77, D78, D79, D80, D81, D82 respectively. In cases where more than one author contributed to a publication those contributors who appeared on the master data file were accorded the relevant fraction of a publication. Thus for example if an individual on the master data file had, during 1978, published two articles with no co-authors, one with one co-author and one with two co-authors that individual's entry for D78 would be 2.83.

As a measure of research output in a given year these observations have a number of serious limitations. One obvious objection which might be raised is that publication in scholarly journals is only a manifestation of research activity and not the activity itself. This argument, although correct, is not to the point. In a prestige maximizing model, university faculty and departments seek to produce that output which generates prestige. It is the assumption of this thesis that it is the quality and quantity of publications which generates prestige for university faculty members. Therefore it could be argued that research can be defined as publication generating activity and the publications thus generated are the true research output. Other objections to the use of these seven variables as measures of research output which are more to the point deal with the problem of aggregaton. The massive literature on using publications to measure research in economics has focused on several problems involved in using the a simple publication count as the measure of research output.(1) The basic problem is that the length of the article, the journal in which it was published, the number of times it was cited and so on all contribute to a determination of the prestige of the article and thus to its value as output. The most common method by which researchers have attempted to overcome these problems is to weight articles either by standardized page length, by subsequent citations, or by quality of journal.(2) Although the main data base used in the study aggregates articles without any weighting system sensitivity studies were conducted using various approaches and the degree and direction of

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(1) A very large number of papers have been written in which journal publications have been used to rank academic departments. Representative among them are: Davis and Papanek (1974); Bell and Seater (1978); House and Yeager (1978); Miller and Tollison (1975); Niemi (1975); Moore (1973); Siegfried (1972); Hogan (1984); and Hirsch et al. (1984). Papers focusing on Canadian universities are Frankena and Bhatia (1973) and Grubel (1981). One important paper in this area is Graves, Marchand and Thompson (1982) who estimate a model very similar to that presented in equation 4-2 for American academics in departments of Economics.

(2) From a review of this literature it appears that there is no consensus on how best to weight publications. It should be noted however that with the execption of Graves, Marchand and Thompson (1982) the literature is primarily directed at ranking academics and departments. It has been demonstrated that small changes to the weighting scheme can greatly affect an individual or a department's ranking. For the purposes of this study these issues are much less crucial.

any possible bias that may result from the approach used in the study are reported in Chapter 7.

As explained in Chapter 3 the observations on these seven variables, D76 to D82, are intended as a proxy for research output. These variables were not used directly in in the regressions. Instead, two transformations of these variables are used to create the variables representing the research output of an individual and that individual's research producing human capital. The former (RESij) is created by summing D81 and D82. This variable is then taken to represent the output of research in the 1981-1982 academic year. The latter (HCij) is created by summing D76, D77, D78, D79 and D80. This variable measires the stock of research producing human capital. It is assumed a priori that the best measure of the ability of an individual faculty member to generate publications is in fact the past publication record of that individual. Faculty members who, either because they have just entered the profession from graduate school or for any other reason, have published very little in the years between 1976 and 1980 were thought, a priori, to have a low probability of publishing in the years 1981-1982. Similarly, those who have published a great deal between 1976 and 1980 were thought to have a high probability of publishing in 1981-82. It should be noted that the quality of publication problem discussed above is not as severe for the relationship between RESij and HCij as for other relationships. This is because there is likely to be a certain continuity in the quality of publications for any one individual. In other words, it is likely that, over time, changes in the research output of any one individual faculty member will result in an increased number of publications, and not simply an increase in the quality of publications.

DEPHCj is created by summing HCij across all individuals within a department and divided by the number of faculty members in that department (SIZEj). This variable is the measure of the average level of human capital in department j. This variable was created for every individual and added to the master data file as the eleventh variable. Like UNIVj and all other university specific variables it takes on only one of 15 values and is the same for all individuals who are employed in a given discipline and the same department.

The source of the final 6 variables in the master data file is a special run of Statistics Canada's data base on university enrolment. It reports total enrolment at each university by field of study (i.e., department), level (Bachelor's, Master's, or Doctoral) and type (full-time or part-time). From these data six university specific variables are created; full-time Bachelor's (FTBAj), part-time Bachelor's (PTBAj), full-time Master's (FTMAj), part-time Master's (PTMAj), full-time Doctoral (FTPHDj), and part-time Doctoral (PTPHDj). Unfortunately, the University of Toronto does not report enrolment data by field of study at the Bachelor's level, so the appropriate value has to be created in an ad hoc manner. This is done by setting the ratio of students to faculty at the University of Toronto equal to the provincial average. While it was feared that this procedure would greatly reduce the validity of the results, extensive sensitivity analysis has found the results of Chapter 5 to be insensitive to estimated values of FTBAj and PTBAj for the University of Toronto, within a reasonable range. The analysis of this result, along with a description of the procedures used and the range over which the results hold, is discussed in Chapter 7.

For most regressions the 6 enrolment variables in the master data file are not used directly, but rather the appropriate variables are created by aggregating full and part-time enrolment and Masters and Doctoral level enrolment. This is done by an arithmetic data transformation statement which weighs full and part time students and sums them to create a single value for enrolment at each level. For simplicity part-time students are assessed a weight of 20 percent of full-time students at all three levels. The three variables thus created are called ENRBAj, ENRMAj, and ENRPHDj and are divided by the relevant value of SIZEj to create AVBAj, AVMAj, and AVPHDj. Again sensitivity analysis is conducted to test the sensitivity of the results to various aggregation procedures and the results are reported in Chapter 7.

4.5 Summary

In this chapter, a model of the production function of individual research output was posited. The use of the estimated parameters of such a model to infer the values of parameters of an unestimated equation of departmental research production was explained. The variables expected to determine individual research output are the individual level of human captial , average departmental levels of human capital and teaching outputs, department size, other personal characteristics (i.e., rank), and the average (per faculty member) levels of other departmental characteristics. The data sources for these variables were given.

In this chapter no functional form of the production function was specified. However, in the discussion of the aggregation procedures involved in interpreting the estimated equation (given in general form as equation 4-2) as a departmental production the function, it was recognized that functional form of the estimated equation may be non-linear. It was specificly recognized that the right-hand side of the estimated equation may include quadratic or cubic terms, and interaction terms between various explanatory variables. Although no specific functional form is implied by the theoretical discussion, it is clear that functional form is at the centre of the policy issues discussed in Chapter 1.

In Chapter 5 various functional forms of the general specification (equation 4-2) are tested against each other in an attempt to determine which functional form is best supported by the data. In addition, standard econometric techniques are employed to ensure consistent and efficient estimates of the parameters. In Chapter 6 the resulting estimates are used to analyse the policy questions of Chapter 1.

CHAPTER 5

THE PRODUCTION FUNCTION FOR UNIVERSITY RESEARCH

5.1 Introduction

In Chapter 1 three proposed solutions to the financial difficulties of Ontario's universities were examined. Each of these solutions has in common two things; first, they have been seriously proposed as possible solutions and second, the effectiveness of the proposals depends on certain assumptions (often implicit) about the nature of academic production. In some cases these assumptions may simply be about the sign or value of a first derivative of the production function, but in some cases it is the value or sign of second derivatives or cross-partials which become important in evaluating the effectiveness of the proposed policies. For this reason, determining the correct functional form of the production function is as important as determining the correct explanatory variables.

In this chapter, the general production function for the research output of faculty members in Departments of Economics, which was outlined in Chapter 4, is estimated. Since no functional form was indicated by the theoretical discussion in Chapter 4, and since the actual functional form is crucial to the analysis of the policy proposals, specification testing is undertaken to determine the 'best' specification. The equation, thus specified, can then be regarded as a maintained hypothesis. Then, in Chapter 6, each of the three policy proposals which were discussed in Chapter 1 are evaluated in the light of this specification. In each case, experiments are performed to determine the extent of potential efficiency gains or cost savings which might be realized from the application of the policy under discussion to Departments of Economics in Ontario, given the constraints imposed by the estimated form of the production function.

5.2 The General Form of the Production Function

Following the discussion of Chapter 4, research output generated by any one individual university faculty member is hypothesised, *a priori*, to be some function of that individual's research-producing human capital, the average level of human capital in the department where the individual is employed, the number of faculty members in the department, the average (per faculty member) number of students enrolled at bachelor's, master's, and doctoral levels in the department, and other, as yet unspecified, departmental and personal characteristics. The general form of this production function is:

$$RESij = g(HCij, DEPHCj, SIZEj, AVBAj, AVMAj, AVPHDj, PCij, DCj) \qquad (5\text{-}1)$$

where:

- RESij : total research output of faculty member i at university j
- HCij : the human capital of faculty member i at university j
- PCij : a vector of personal characteristics of faculty member i at university j
- DEPHCj : average level of human capital at university j
- AVBAj : enrolment at the bachelor's level per faculty member at universty j

AVMAj : enrolment at the master's level per faculty member at university j

AVPHDj : enrolment at the doctoral level per faculty member at university j

SIZEj : total number of faculty members employed at university j

PCj : a vector of average levels of personal characteristics of faculty members employed at university j

DCj : a vector of average levels of departmental characteristics of at university j

and j = 1 . . . N

i = 1 . . . SIZEj

The use of this production function is predicated on the model of academic production outlined in Chapters 3 and 4 in which research is the only output endogenously determined, and the appropriate unit of analysis is the individual faculty member, but where attributes of the department in which the faculty member works are relevant to the production process.

As indicated in Chapter 4 the use of these particular variables to explain the research output of individual faculty members has a number of advantages. In particular the decision to enter all departmental variables as per faculty averages and then include the number of faculty members as a separate variable, rather than include only total values of departmental variables, has theoretical as well as practical advantages. The other members of a department affect the research output of any one individual member in a number of ways. For a given number of students, the larger the number of faculty the more time each individual faculty member has for research, cet. par. As well, the more faculty members there are in a department the more likely it is that any one individual will have collegues working in the same area who may be able to provide input into his or her research. By employing the variables AVBA, AVMA, AVPHD, and SIZE, these two effects are clearly distinguished. The human capital of other faculty members will indicate the quality of input available from other faculty. DEPHC measures the average level of human capital in the department. By employing both DEPHC and SIZE the impact of more collegues and the impact of collegues with higher human capital is distinguished. Finally, other departmental characteristics such as support staff and equipment are taken as per faculty averages because it is not the total amount of such inputs in a department, but the amount available to each faculty member, which is important.

In addition to these theoretical reasons, this approach has the practical advantage that, when interpreted as a production function of the average level of departmental research, all independent variables are departmental averages except SIZE, which can then be taken as a measure of returns to scale.

5.3 Model Specification: Nested Hypothesis Tests

Ignoring for the moment the problem of the unspecified vector of departmental and personal variables, DC and PC, which will be dealt with in a later section, there are six independent variables. There is no strong presumption that the form of the production function is linear.

On the contrary, non-linearity is quite possible in the relationship between RES and HC, DEPHC, and SIZE. Since the existence of a non-linear relationship between RES and any of these three variables will have important implications for the assessment of the policy options (this point will be more fully explained in subsequent sections) the original estimating equation will have, as right-hand side variables, terms representing each of these three terms squared. These squared terms are denoted HC2, DEPHC2, and SIZE2. In addition to this type of nonlinearity, if there is any jointness in production between doctoral teaching and research the marginal product d(RES)/d(HC) may be a function of AVPHD. For this reason the interaction term HC*AVPHD will also be included. Similarly, the marginal product d(RES)/d(HC) may also be a function of SIZE and/or DEPHC. Thus the interaction terms HC*SIZE and HC*DEPHC are also included.

The resulting equation, which is linear in the coefficients, can be expressed as:

$$\begin{aligned} RESij = {} & a + b1(HCij) + b2(HC2ij) + b3(DEPHCj) + b4(DEPHC2j) \\ & + b5(SIZEj) + b6(SIZE2j) + b7(AVBAj) + b8(AVMAj) \\ & + b9(AVPHDj) + b10(HCij*AVPHDj) + b11(HCij*SIZEj) \\ & + b12(HCij*DEPHCj) \end{aligned} \tag{5-2}$$

This equation is estimated using OLS, first in unrestricted form, and then with the imposition of various linear restrictions. The results of this procedure are presented in Table 5-1.

TABLE 5-1: **OLS Estimation of the Production Function with Data from Departments of Economics**

Variables	Regressions			
	1	2	3	4
HC	.014272		.171130	.159130
	(0.150)		(4.564)	(9.641)
HC2	-.001124		-.000968	
	(-0.387)		(-0.357)	
DEPHC	.284580		.280320	.198410
	(0.959)		(0.964)	(1.795)
DEPHC2	-.065103		-.025735	
	(-0.752)		(-0.357)	
SIZE	.029216	.030889	.035277	.034827
	(2.560)	(3.045)	(3.137)	(3.125)
SIZE2	-.000244	-.000258	-.000272	-.000263
	(-2.178)	(-2.683)	(-2.426)	(-2.421)
AVBA	-.012285	-.014649	-.013692	-.013919
	(-1.446)	(-1.860)	(-1.608)	(-1.644)
AVMA	-.082007	-.112940	-.114440	-.119580
	(-0.673)	(-0.986)	(-0.938)	(-0.989)
AVPHD	.015027	.050275	-.302370	-.332380
	(0.058)	(0.258)	(-1.288)	(1.549)
HC*AVPHD	-.148290	-.161610		
	(-2.720)	(-3.764)		
HC*SIZE	.001529	.001728		
	(1.396)	(1.907)		
HC*DEPHC	.092346	.094477		
	(2.248)	(6.535)		
INTER-CEPT	-.231780	.025158	-.328120	-.253630
	(-0.709)	(0.118)	(-1.003)	(-1.027)
R-SQUARE	.2993	.2971	.2827	.2823
F-STAT	14.058	21.076	17.431	22.475
RSS	417.28	418.60	427.13	427.39
d.f.	395	399	398	400
SEE	1.0564	1.0243	1.0359	1.0337

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

The first equation in Table 5-1 gives the results of the unrestricted OLS regression. The result is a strong regression, with an overall F-statistic of 14.058 and an R-square statistic of .2993. Since the regression is nonlinear in the variables, many of the relevant partial derivatives atives are expressed as functions of one or more right-hand side variables and must be evaluated at the means of those variables. (The means of all variables are given in Table A-1 in the Appendix). Performing this task indicates that d(RES)/d(HC) = .1491284 with a second derivative of -.002248. This implies that the marginal product of human capital in the production of research is positive but diminishing at the mean values of all variables. This result is in accord with the standard theory of production. The other two inputs, DEPHC and SIZE should similarly have positive first partial derivatives.(1) Both marginal products are positive when evaluated at the means, with d(RES)/d(DEPHC) = .2080921 and d(RES)/d(SIZE) = .0111633. In both cases marginal products are diminishing as the second derivatives are -.130206 for DEPHC and -.00048798 for SIZE. The change in RES which results from a marginal increase in AVBA or from a marginal increase in AVMA are simply equal to the values of the estimated

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(1) It should be noted that, when interpreted directly as a production function of individual research output, SIZE is simply an input. Thus d(RES)/d(SIZE) measures the change in one individual's research output resulting from a marginal increase in the number of faculty employed in the same department, holding the individual's own human capital, the average level of departmental human capital, and the average (per faculty) level of student enrolments constant. Unlike the case where the regression is interpreted as a production function for the average level of departmental research, this marginal has no implications for returns to scale.

parameters b7 and b8 (-.012285 and -.082007 respectively). Finally, the partial d(RES)/d(AVPHD), when evaluated at the means is equal to -.2902724.

Thus, the values of all the first partial derivatives of the production function conform to the predicted signs. However, one problem with regression #1 is the large number of estimated coefficients which are not statistically significant.(1) This result is not too surprising in an equation in which many of the explanatory variables appear in linear, quadratic, and interactive form since the joint variance between these terms will reduce the precision (reduce the variance) of the OLS estimators. A logical second step would be to re-estimate the equation restricting b1 = b2 = b3 = b4 = 0. If these restrictions do not significantly reduce the amount of variance in the dependent variable which is explained by the equation, the hypothesis that the restriction is 'true' cannot be rejected. To the extent that these dropped variables are correlated with the remaining variables, the efficiency of the estimator should be improved. Regression #2 in Table 5-1 presents the results of this estimation.

A comparison of Regression #1 and regression #2 suggests that the

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(1) For the purposes of this discussion an estimated coefficient will be described as significant if the probability of having attained that estimate given that the true value is zero, is less than 10 percent. This corresponds to a t-statistic of 1.65 for a two-tailed test. This significance level is, of course, arbitrary. The appropriate t-statistic values for significance levels of 5 percent and 1 percent are 1.97 and 2.60 respectively (two-tailed tests).

latter is the superior regression. The increase in the residual sum of squares is only 1.32 and the F-statistic for the test of the null hypothesis that the restriction is 'true' is .3124, which means that the null hypothesis cannot be rejected at the one percent significance level. In this regression the first partial derivatives are: d(RES)/d(HC) = .1420539, d(RES)/d(DEPHC) = .1945092, d(RES)/d(SIZE) = .012054, d(RES)/d(AVBA) = -.014649, d(RES)/d(AVMA) = -.11294, and d(RES)/d(AVPHD) = -.2799726. Again, all of these results agree with prior expectations, and, in fact, are very similar to the values of the first derivatives taken from regression #1. As expected, the efficiency of the estimators is improved by this procedure and now the coefficients of all right-hand side variables are significant except AVMA and AVPHD, although the interaction HC*AVPHD has a significant coefficient.

One difficulty that often appears in cases where multi-collinearity is suspected is that variables which appear to be insignificant when included in the general model may be significant in a restricted estimation. Thus it is possible that the equation may fit just as well with the interaction terms restricted (i.e., b10 = b11 = b12 = 0) as it did when the first four terms were restricted. To examine this possibility the model was restimated with the above restrictions and with the restrictions that b2 = b4 = b10 = b11 = b12 = 0. These two estimations are given as regression #3 and regression #4 in Table 5-1.

In regression #3, in which the coefficients on all interaction terms have been set to zero, b1, the coefficient on HC, is now highly significant. This is not surprising since an examination the previous regressions indicates a strong positive relationship between RES and HC. With no interaction terms, all of that relationship is captured by the HC term. The relevant first partials are: d(RES)/d(HC) = .1671434, d(RES)/d(DEPHC) = .1749301, d(RES)/d(SIZE) = .0116419, d(RES)/d(AVBA) = -.013692, d(RES)/d(AVMA) = -.11444, and d(RES/d(AVPHD) = -.30237. Again these terms all have the expected signs and all are very similar in value to the partials derived from the first two regressions. Testing the linear hypothesis that b10 = b11 = b12 = 0 generates a F-statistic of 3.1080. With 3 restrictions and 395 degrees of freedom we are able to reject the hypothesis at a 5 percent significance level. Since we were unable to reject the hypothesis that b1 = b2 = b3 = b4 = 0, regression #3 is clearly inferior to both regression #1 and regression #2.

In regression #4 all variables except SIZE enter linearly, with no interaction terms. Except for d(RES)/d(SIZE), all first partials are equal to the values of the relevant coefficient. They are: d(RES)/d(HC) = .15913, d(RES)/d(DEPHC) = .19841, d(RES)/d(SIZE) = .0119742, d(RES)/d(AVBA) = -.013919, d(RES)/d(AVMA) = -.11958, and d(RES)/d(AVPHD) = -.33238. Once again the signs and values of the first partials are consistent with previous regressions. The F-test of the null hypothesis that b2 = b4 = b10 = b11 = b12 = 0 generates a value of 1.914 which is not significant at the 5 percent level. In other words we are not able to reject the null hypothesis. Thus, like regression #2, this equation is superior to the unrestricted equation in which it was nested.

It was thought, a priori, that both HC and DEPHC are inputs into the production of an individual faculty member's production of research output. The results of these four regressions tend to confirm this presumption as both variables are significant explanatory variables, either alone or interactively with each other. Further, the estimated values for d(RES)/d(HC) range from .1420539 to .1671434 and for d(RES)/d(AVHC) from .1749301 to .2080921. These ranges (.0250895 and .033102, respectively) are quite small. For example, in regression #4, in which the partials are simply equal to the values of the relevant coefficients, the estimated standard errors for the two coefficients are .016506 and .11056, respectively. Thus, it does not appear that the estimated values of the first partials are particularly sensitive to the choice of specification. On the other hand, the functional form does matter when it comes to second derivatives and cross partials, which play an important role when it comes to discussing the policy implications of the results. Therefore the matter cannot be left here. It is important to determine which specification best fits the data. Thus non-nested techniques are needed to compare different specifications.(1)

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(1) It should be noted that the four specifications reported in Table 5-1 constitute restrictions on an even more general specification, one in which all variables enter directly, squared, and in interaction with HC. In fact nested hypothesis testing was performed with this general equation and it was found that that no specification can be found from this 'kitchen sink' procedure which outperforms the specifications of Table 5-1. These regressions, and the relevant F-statistics, are reported in Table A-2 and Table A-3 in the Appendix.

5.4 Model Specification: Non-nested Hypothesis Tests

Of the three restricted equations reported in Table 5-1, two can be said to be superior to the the unrestricted regression (regression #1). These are regression #2 in which the first four terms are excluded, and regression #4, which is linear in all variables except SIZE. As noted above, the values of the first partial derivatives for all variables are very similar in the two regressions, although in regression #4 all cross partials are constrained to be zero. However, interpreted as a departmental production function (i.e., an equation which explains of the average level of departmental research output), there are very important differences between the two equations. For example, interpreting regression #2 as a departmental production function (and using the symbols of equation 5-2 for simplicity) the following equation is obtained:

$$\begin{aligned} AVRESj &= a + b5(SIZEj) + b6(SIZE2j) + b7(AVBAj) + b8(AVMAj) \\ &\quad + b9(AVPHDj) + b10(DEPHCj*AVPHDj) + b11(DEPHCj*SIZEj) \\ &\quad + b12(DEPHC2j) \qquad (5\text{-}3) \end{aligned}$$

In equation 5-3 the process of aggregating the production function for individual research output over all members of a department and then dividing by the total number of members in that department turns the last three terms into interaction terms between departmental averages. A similar process can be applied to regession #4 in Table 5-1, yielding:

$$\text{AVRESj} = a + (b1 + b3)(\text{DEPHCj}) + b5(\text{SIZEj}) + b6(\text{SIZE2j}) + b7(\text{AVBAj}) + b8(\text{AVMAj}) + b9(\text{AVPHDj}) \qquad (5\text{-}4)$$

Thus in addition to the interaction terms, the two equations differ in that regression #2, when interpreted as a departmental production function, is non-linear in DEPHC, while regression #4 is linear in DEPHC.

Since regression #2 and regression #4 are not nested, classical hypothesis testing cannot be performed to compare the two results. Instead, a non-nested technique is required. The most straight-forward non-nested test is the residual variance test proposed by Theil (1971). Theil argues that if one of two competing models is true, the expected value of its residual variance will be lower than the expected value of the residual variance of the false model. Thus, a comparison of the estimated variance of the estimate provides a criterion for model selection. In this case, the residual variance is lower for regression #2 (1.0491) than it is for regression #4 (1.0684). However, this approach suffers two problems. First, while the expected value of the residual variance will be lower for the true model, any individual estimate of the variance may be higher than the estimate of the variance for a false model. Second, this test assumes that one of the competing models is true, while in fact neither may be.

A second approach to non-nested testing involves artificial nesting. There are now a vast number of possible tests which have been proposed in the literature along these lines. One of these techniques, proposed by Davidson and McKinnon (1981) is known as the J-test. This test proceeds along the following lines: If there are two competing hypotheses, H1: E(y) = XB, and H2: E(y) = ZD, where the matrices X and Z may contain common columns, the artificial regression equations are:

$y = (1-a)XB + aZd + e$; and

$y = (1-c)ZD + cXb + e'$

where a and c are unknown parameters and d and b are the OLS estimators of D and B respectively. The tests of H1 and H2 are now standard F-tests of the hypotheses that $a = 0$ and $c = 0$. Thus, each hypothesis must be tested against the other. This means that, not only is it possible to reject one hypothesis in favour of the other, it is also possible to reject each hypothesis against the other, or, be unable to reject either hypothesis against the other. The J test was applied to the two hypotheses implied by regression #2 and regression #4 in Table 5-1.

Since each hypothesis must be tested against the other, two artificial regressions were run. In the first regression specification #2 is tested against specification #4 (from Table 5-1). If the value of the parameter a is significantly different from zero, the artificial regression does not reduce to specification #2. This procedure yields an estimate for the parameter a of .30988 with a t-statistic of .68595. Thus the hypothesis that $a = 0$ cannot be rejected and we cannot reject specification #2 when tested against specification #4. In the second regression, specification #4 was tested against specification #2. In this case if the value of the parameter c is significantly different from zero, the artificial regression does not reduce to specification #4. This trial yields an estimated value for c of .89807 with a t-statistic of 2.9820. (The full regression results are reported in Table A-4, in the Appendix). Thus, the hypothesis that c = 0 can be rejected at the 1 percent level. This implies that the artifical equation does not reduce to specification #4. The hypothesis that specification #4 is true is rejected against the alternative hypothesis that specification #2 is true, but the hypothesis that specification #2 is true cannot be rejected against the alternative hypothesis that specification #4 is true.

Thus, both the residual variance test and the J-test reject regression #4 in Table 5-1 against the alternative hypothesis implied by regression #2. The latter test is particularly important because it also demonstrated that regression #2 could not be rejected against the alternate hypothesis.

5.5 The Structure of the Error Term

The specification of regression #2 in Table 5-1, which implies a departmental production function of the form expressed in equation 5-3, can now be taken as the maintained hypothesis. However, before it can be used to evaluate the policy proposals of Chapter 1, several other statistical aspects of the equation must be examined.

The statistical properties of the OLS estimator depend on a set of classical assumptions, which may be split into two types; assumptions about the structural part of the model, and assumptions about the disturbance term. Failure of the first type of assumptions results from the omission of relevant independent variables, incorrect functional form, or stochastic regressors. Failure of the second type of assumptions results if the disturbance terms are non-normal or non-spherical. Typically, the second type of failure leads to consistent but inefficient estimators while failure of the first type causes the OLS estimator to be inconsistent. Therefore it is important to test these assumptions and, where possible, correct for deviations from the classical assumptions. In the sections that follow, the maintained equation will be tested for failure of the stochastic specification and the structural specification.

The classical assumptions concerning the structure of the error term (u) in the regression model, $y = XB + u$, are that the error term has zero mean, constant variance, and zero covariance across observations. A non-zero mean is not generally considered a problem since it will only affect the estimate of the intercept term and, for the purposes of simulations or experiments, the biased estimator of the intercept would be preferred. It is highly unlikely that the assumption of zero covariance would be violated in a cross-sectional study of this type. The standard tests for this problem involve ordering all observations (in a time-series study observations come pre-ordered) and checking the relationships between residuals from observation to observation. However, in a study of this type, any test of this nature is more a test of mis-specification rather than of non-zero covariances of the error term, and should be considered later, with other tests of mis-specification.

However, violation of the assumption of homoskedasticity is possible, even likely, in studies using cross-sectional microeconomic data. In the case of the model being estimated here, it is probable that the variance of the disturbance term will be larger for individuals with more human capital than for individuals with less human capital. Thus, it is necessary to test for the presence of heteroskedasticity and, if found, appropriate corrective procedures must be undertaken.

The standard tests for heteroskedasticity are those developed by Goldfeld and Quandt (1965) and by Breusch and Pagan (1979). However, both of these techniques are problematic in this case. The Goldfeld-Quandt test requires ranking observations by the independent variable that is thought to be correlated to the variance of the disturbance term, which in this case is HC, and then splitting the sample into three groups. However because HC takes on the value of zero for over one third of the observations it was felt that this test would be inappropriate. The Breusch-Pagan test, on the other hand, has been shown (Koenker, 1981) to be very sensitive to violations of the assumption that the disturbances are normally distributed. Although no test of normality the disturbances has yet been performed (in fact this testing should be performed after the data have been transformed to remove any heteroskedasticity) it is unwise to assume normality of disturbances at this stage. For these reasons, the test chosen is one developed by White (1980), which has been shown to be equivalent to the Breusch-Pagan test when modified to remove its dependence on the assumption of normality (Waldman, 1983). This test requires regressing the squares of the OLS residuals (from the regression to be tested for heteroskedasticity) against all the independent variables in the original model, their squares, and all possible interaction terms. Under the null hypothesis of no heteroskedasticity the R-squared statistic from this regression, multiplied by the number of observations, has a chi-squared distribution with degrees of freedom equal to the number of right-hand side variables (in this case, 30). This test was applied to the residuals from regression #2 in Table 5-1. The resulting chi-squared statistic was found to be 320.2, which is significant at the 0.25 percent level. Thus, the null hypothesis of no heteroskedasticity is rejected.

Although the presence of heteroskedasticity does not cause the OLS estimators to be inconsistent it does reduce their efficiency. The efficiency of the estimators can be improved by running an appropriately specified GLS estimation. However, in order to do this it is necessary to estimate the relative sizes of the diagonal elements of the disturbance matrix. This can be done by regressing the absolute values of the disturbances on HC as suggested by Gleisjer (1969). The result is given as equation 5-5 below:

$$\underset{}{abs(e)} = \underset{(11.9)}{.51227} + \underset{(6.68)}{.15632(HC)} - \underset{(4.43)}{.0076565(HC2)} \quad (5\text{-}5)$$

R-SQUARE = .1247

The dependent variable in equation 5-5 is the absolute values of the OLS residuals from regression #2 on Table 5-1, and the numbers in brackets are t-statistics. Both HC and HC2 prove to be significantly different from zero at the 1 percent confidence level, as expected. This too is a test of heteroskedasticity, however, the White test is far more general in that it does not require a specification of the form of heteroskedasticity.

The results of equation 5-5 can be used to estimate the relative sizes of the diagonals of the distribution matrix. A feasible GLS estimation can now be performed using the squares of the predicted values of the dependent variable in equation 5-5 as the diagonal elements in the unknown disturbance matrix. The results of this estimation are given in equation 5-6.

$$
\begin{aligned}
RESij = &- \underset{(0.050)}{.008368} + \underset{(3.914)}{.032383}(SIZEj) - \underset{(3.849)}{.000304}(SIZE2j) \\
&- \underset{(2.394)}{.015159}(AVBAj) - \underset{(1.243)}{.11554}(AVMAj) + \underset{(1.008)}{.15831}(AVPHDj) \\
&- \underset{(3.606)}{.21476}(HCij*AVPHDj) + \underset{(1.984)}{.002314}(HCij*SIZEj) \\
&+ \underset{(7.607)}{.10626}(HCij*DEPHCj) \qquad (5\text{-}6)
\end{aligned}
$$

R-SQUARE = .2960

A comparison of equation 5-6 and regression # 2 in Table 5-1 yields the expected implications. Since OLS is not inconsistent we do not expect any of the estimated values of the coefficients from the GLS regression to be outside the one percent confidence intervals of the original estimates, and none are. However, we do expect a reduction in the estimated values of the standard errors, and this is reflected in the generally higher t-statistics reported in equation 5-6. In equation 5-6, all right-hand side variables are significantly different from zero at the 5 percent level except AVMA and AVPHD, whereas in Regression #2 in Table 5-1 neither AVBA nor HC*SIZE are significant at that level.

The final aspect of the stochastic specification which will be dealt with is the assumption that the disturbances are distributed normally. In general, "the violation of the assumption of normality does not appear to have very serious consequences for least squared estimation" (Kmenta, 1986, p.262). Neither the Gauss-Markov theorem nor Aitken's theorem, which prove the minimum variance property for the OLS and GLS estimators, among the class of linear unbiased estimators, requires the assumption of normality. However, if the disturbance term in not normally distributed, other estimators (although not linear unbiased estimators) may be more efficient than least squares estimators. The goodness-of-fit test was applied to the residuals of equation 5-6, yielding a test statistic of 269.95. This statistic has a chi-square distribution with 19 degrees of freedom, which means that the null hypothesis of normal disturbances can be rejected at the 1 percent level.

This result is not surprising given the nature of the data. Since the data are censored, in the sense that no observation on the dependent variable can be below zero, and since the predicted values of the dependent variable range from -.6 to 4.6, the positive skewness of the residuals is understandable. One possible solution to this problem is to use the TOBIT nonlinear model, which uses the information about the censored nature of the data, rather than OLS, which does not use that information. However, if the TOBIT statistical model is appropriate, the linear model estimated with least squares techniques is mis-specified and the least squares estimators are biased. Thus, the question of whether the TOBIT statistical model is the appropriate one for this particular problem is just one of several issues concerning the specification which needs to be examined.

The censored normal regression model assumes that the error term is normally distributed, but that the dependent variable is censored so that only (in this case) non-negative values can be recorded. A maximum likelihood estimator for this model (the TOBIT estimator) is consistent, while the least squares estimators are biased. In Table 5-2, the results obtained from estimating the model using the linear functional form with OLS and GLS, and from using the non-linear TOBIT model, are compared. Since the actual non-linear regression equation run when the TOBIT statistical model is assumed cannot be directly compared to the OLS and GLS linear equations, the TOBIT coefficients reported in Table 5-2 have been normalized.

It is clear from an analysis of Table 5-2 that the estimated values of the coefficients are not highly sensitive to TOBIT vs. LS specifications. The normalized estimated coefficients which result from the TOBIT regression are not significantly different from those of the OLS and GLS regressions. It appears that if the evident non-normality of the residuals is actually a result of a mis-specified equation (mis-specified by not using TOBIT where it is required), the effects on

TABLE 5-2: Comparison of OLS, GLS, and TOBIT Estimates of the Production Function: Maintained Specification

Variables	Regressions		
	OLS	GLS	TOBIT
SIZE	.030889 (3.046)	.032383 (3.931)	.035327 (2.928)
SIZE2	-.000258 (-2.683)	-.000304 (-3.849)	-.000321 (-2.820)
AVBA	-.014649 (-1.860)	-.015159 (-2.394)	-.016618 (-1.660)
AVMA	-.112940 (-0.976)	-.115540 (-1.243)	-.116800 (-0.785)
AVPHD	.050275 (0.258)	.158310 (1.008)	.271940 (1.194)
HC*AVPHD	-.161610 (-3.764)	-.214760 (-3.606)	-.149190 (-3.322)
HC*SIZE	.001728 (1.907)	.002314 (1.984)	.002001 (2.148)
HC*DEPHC	.094477 (6.535)	.106260 (7.607)	.071725 (4.754)
INTER- CEPT	.025158 (0.118)	-.008368 (-0.051)	-1.09750 (-3.722)
R-SQUARE	.2971	.2960	.2725

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

the estimated values of the coefficients are slight. On the other hand, there is nothing in these results to suggest other than that the linear (in the coefficients) model is correct, in which case the least squares estimators (OLS and GLS) are consistent. The evident non-normality of the disturbance term causes problems for hypothesis testing with small samples, however the standard t-statistics and F-statistics do have asymptotic validity. With nearly 400 degrees of freedom, these test statistics can safely be employed.

5.6 Omitted Explanatory Variables

As Kramer, et al. (1985) point out; "the complications that arise from non-well behaved errors seem relatively minor as compared to the consequences of a wrong specification of what might conveniently be called the structural part of the model". Thus far, two of the tests performed can be interpreted as specification tests. First, the maintained hypothesis was tested against the alternative hypothesis that the specification of regression #4 in Table 5-1 is the correct specification. This was done using the J test, which, as Pagan (1984) and McKinnon (1983) point out, is an effective specification test since it is possible for both specifications to be rejected against the other. Second, the maintained hypothesis was tested against the hypothesis that the true statistical model was the censored normal regression model. The stability of the coefficients support the maintained hypothesis. However, because of the importance of the structural specification, several more tests will be performed before the equation is used to infer potential efficiency gains from alternative policies.

All of the regressions which have so far been reported focus on the problem of finding the correct functional form which relates RES to HC, DEPHC, SIZE, AVBA, AVMA, and AVPHD, on the assumption that these are the correct explanatory variables. The analysis which has been performed confirms that these variables are appropriate right-hand side variables. It also strongly indicates that the specification of equation 5-6 is the appropriate one. However, a specification error which is at least as important as incorrect functional form is that of omited relevant variables. In general, the omission of relevant explanatory variables will bias the estimators of the included variables.

In equation 5-1, which gives the general form of the production function for university research, are two unspecified vectors of explanatory variables; PC and DC. These vectors were meant to represent personal and departmental characteristics, respectively, which would explain variation in individual research output. Because of the nature of the variable representing human capital (HC), it is likely that any personal characteristic which systematically influences research output would already be captured in the measured value of HC. This is likely to be the case if human capital is measured by the past publication record of the faculty member, as is done here, or if human capital is measured by the salary of the faculty member, as has been done in other studies (Graves et al., 1982). However, one personal characteristic which might influence the general relationship between RES and HC is the academic rank of the individual faculty member. For example, a Lecturer or Assistant Professor may have a limited publication record because he or she may be a relatively recent graduate. On the other hand, an Associate Professor's poor publication record is more likely to be truly indicative of low research-producing human capital.

In order to allow for the possible effects of rank a series of new variables was introduced. First, three intercept dummies were created, one for each rank except Full Professor. These dummy variables were denoted D2, D3, and D4 for Associate Professor, Assistant Professor, and Rank below Assistant, respectively. The dummies took on the values 1 when the faculty member held the relevant rank and zero otherwise. In addition, three slope dummies were created by multiplying the intercept dummies by HC. The resulting variables were labeled 2HC, 3HC, and 4HC. These three slope dummies were then used to create slope dummy variables for the three interaction terms. Thus, 2HC*AVPHD, 3HC*AVPHD, and 4HC*AVPHD represent the interaction term between human capital and AVPHD for Associate Professors, Assistant Professors, and rank below Assistants, respectively. In a similar manner 2HC*SIZE, 3HC*SIZE, 4HC*SIZE, 2HC*DEPHC, 3HC*DEPHC, and 4HC*DEPHC were created. The specification of equation 5-6 was then re-estimated with the inclusion of the slope dunmmies and the three intercept dummies using OLS. If the estimated coefficients of the dummies are close to zero it means that there is no difference in the intercept or the interaction coefficients for faculty of different rank, while if any of the dummies is significantly different from zero it means that the basic production relationship is different for faculty of different rank. The values of the estimated dummy coefficients can be interpreted as the difference between the true coefficient of that variable for the relevant rank and the coefficient for full Professors. The results of this procedure are given in Table 5-3.

Regression #1 in Table 5-3 is an unrestricted equation in which the intercept of the equation and the coefficients on all interaction terms are allowed to differ for faculty of different rank. In regression #2 the intercept is constrained to be the same for all ranks, in regression #3 the coefficient on all interaction terms is constrained to be the same for all ranks, while in regression #4 to regression #6 HC*AVPHD, HC*SIZE, and HC*DEPHC in turn are allowed to differ between ranks while all other dummies are omitted. Finally, in regression #7 all dummies are constrained to be zero. Thus, this regression is the same as regression #2 in Table 5-1 or the first column in Table 5-2.

An examination of the regression results presented in Table 5-3 strongly suggests that the inclusion of rank dummies have very little impact on the estimated values of the other coefficients or on the significance of the equation as a whole. For example, performing the usual F test for the validity of restrictions generates the result that we cannot reject the hypothesis that the restrictions of regression #7 are true (F-statistic = 1.098). In fact, none of the sets of restrictions embodied in regressions #2 through #7 can be rejected at the 5 percent level.

TABLE 5-3: OLS Estimation of Production Function with RANK dummies

Variables	Regressions						
	1	2	3	4	5	6	7
SIZE	.026703 (2.567)	.026571 (2.589)	.028530 (2.771)	.027892 (2.762)	.026767 (2.643)	.028162 (2.783)	.030889 (3.046)
SIZE2	-.000228 (-2.332)	-.000232 (-2.400)	-.000234 (-2.417)	-.000231 (-2.423)	-.000230 (-2 414)	-.000231 (-2.416)	-.000258 (-2.683)
AVBA	- 013831 (-1.752)	-.013977 (-1.778)	-.014190 (-1.802)	-.013608 (-1.742)	-.014077 (-1.805)	-.014447 (-1.848)	-.014649 (-1 860)
AVMA	-.118540 (-0.995)	-.107960 (-0.930)	-.094768 (-0.805)	-.112600 (-0.982)	-.102330 (-0 893)	-1.1880 (-0.886)	-.112940 (-0.976)
AVPHD	.067020 (0.331)	.081702 (0.411)	.068988 (0.351)	.032885 (0 169)	.071302 (0 369)	.042851 (0.220)	.050275 (0.258)
HC*AVPHD	-.172590 (-3.577)	-.174490 (-3.704)	-.169540 (-3.845)	-.184560 (-4.156)	-.173370 (-4.042)	-.174340 (-4.003)	-.161610 (-3.764)
2HC*AVPHD	.049988 (0.536)	.035074 (0.391)		.056260 (1.976)			
3HC*AVPHD	.112790 (0.270)	.112280 (0.272)		.388880 (2.329)			
4HC*AVPHD	-.965040 (-0.804)	-.861710 (-0.725)		-.040317 (-0.291)			
HC*SIZE	.001848 (1.756)	.001926 (1.859)	001869 (2.008)	.002350 (2.462)	.002095 (2 301)	.002207 (2.313)	.001728 (1.907)
2HC*SIZE	001787 (0.903)	.002120 (1.119)			.001537 (2 167)		
3HC*SIZE	.005212 (0.546)	.005417 (0.575)			.008973 (2.424)		
4HC*SIZE	.019503 (1.210)	.017785 (1.120)			.000198 (0.059)		
HC*DEPHC	.094843 (5.718)	.094209 (5.953)	.096726 (6.608)	.088436 (6.023)	.089044 (6 132)	.087111 (5.738)	.094477 (6.535)
2HC*DEPHC	-.031683 (-0.916)	- 027394 (-0.821)				.019846 (1 597)	
3HC*DEPHC	.034858 (0.177)	.028014 (0.145)				.163700 (2.315)	
4HC*DEPHC	100330 (0.266)	.061499 (0.165)				-.036090 (-2.315)	
INTER-CEPT	065891 (0 281)	061307 (0.289)	-.056749 (-0.249)	053223 (0 251)	051607 (0 244)	033908 (0.160)	025158 (0.118)
D2	.057118 (0.359)		.167810 (1.275)				
D3	-.012410 (-0.073)		.164090 (1.074)				
D4	-.114400 (-0.568)		-.046301 (-0.250)				
R-SQUARE	.3202	.3189	.3018	.3127	.3143	3107	.2971
F-STAT	9.114	10.743	15.561	16.380	16.498	16.230	21.076
RSS	404.82	405.57	415.77	409.27	408.35	410.45	418.60
d.f.	387	390	396	396	396	396	399
SEE	1.0228	1.0198	1.0247	1.0166	1.0155	1.0181	1.0243

Dependent variable· RES. Figures in brackets are t-statistics.
Critical t values are: 10% - 1.65: 5% - 1.97. 1% - 2.60.

In addition to the vector of personal variables, PC, the general form of the production function (equation 5-1) includes a vector of departmental characteristics, DC. These potential variables were intended to measure the amount of teaching and research support available to individual faculty members at different universities. Although departmental observations on such support facilities are not available, it was possible to obtain information on university-wide expenditures on support items from the Committee of Finance Officers's annual report (CFO, 1981-82). Thus, for each of three categories (non-faculty salaries and wages, library acquisitions, and academic computing costs) the total university expenditure divided by the total number of faculty employed at the university was calculated. This figure was then used as a proxy for the university's level of per faculty support in each catagory. It is obvious, however, that these are very imperfect proxies for departmental support levels.

The production function for university research is re-estimated using the functional form of equation 5-6, and adding each of the proxy variables singly, and then together. The results of these estimations, using OLS, are reported in Table 5-4.

The results presented in Table 5-4 give absolutely no support to the hypothesis that any of the proxy variables significantly influence the variation in individual research output. This result can be interpreted in one of two ways. It could be interpreted to indicate that departmental support levels are not an important factor in determining the level of research output produced by faculty members in

TABLE 5-4: OLS Estimation of Production Function with Support Proxies

Variables	Regressions				
	1	2	3	4	5
SIZE	.031045 (3.031)	.031819 (3.083)	.030712 (3.031)	.028916 (2.454)	.030889 (3.046)
SIZE2	-.000260 (-2.594)	-.000257 (-2.687)	-.000258 (-2.692)	-.000230 (-2.017)	-.000258 (-2.683)
AVBA	-.015080 (-1.546)	-.015896 (-1.903)	-.014641 (-1.861)	-.009322 (-0.578)	-.014649 (-1.860)
AVMA	-.114540 (-0.970)	-.100740 (-0.847)	-.007830 (-1.015)	-.104610 (-0.858)	-.112940 (-0.976)
AVPHD	.051291 (0.262)	.022000 (0.107)	.037782 (0.193)	-.000361 (-0.002)	.050275 (0.258)
HC*AVPHD	-.161270 (-3.723)	-.160460 (-3.733)	-.159130 (-3.681)	-.160550 (-3.693)	-.161610 (-3.764)
HC*SIZE	.001726 (1.906)	.001695 (1.866)	.001712 (1.891)	.001700 (1.868)	.001728 (1.907)
HC*DEPHC	.094302 (6.397)	.094646 (6.557)	.093448 (6.396)	.094464 (6.393)	.094477 (6.535)
NFSW	.003299 (0.071)			-.042310 (-0.448)	
LIBACQ		.064187 (0.437)		-.002427 (-0.012)	
COMP			.047843 (0.467)	.123630 (0.226)	
INTER- CEPT	.006136 (0.0180)	-.122320 (-0.306)	-.057880 (-0.209)	.057862 (0.098)	.025158 (0.118)
R-SQUARE	.2971	.2974	.2975	.2979	.2971
F-STAT	18.690	18.719	18.724	15.278	21.076
RSS	418.58	418.39	418.36	418.07	418.60
d.f.	398	398	398	396	399
SEE	1.0255	1.0253	1.0253	1.0275	1.0243

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

Departments of Economics. This seems unlikely, although these results certainly do not refute it. On the other hand, they can be interpreted to suggest that the the university-wide support levels simply do not reflect the relative levels of support in Departments of Economics. In the work of Graves et al. (1982), using U.S. data and estimating the departmental production function directly, data on actual departmental expenditures on support items were obtained. They find that that the ratio of secretaries to faculty is a significantly positive factor in the average level of research output, but other support services are not significant. It is quite possible that if data on departmental support expenditures could have been obtained for this study some of them may have proven significant. However, the stability of the estimated coefficients in all regressions so far reported stongly suggests that the potential bias resulting from this omission is slight.

The analysis performed above, and reported in Table 5-3 and 5-4 give strong support to the position that the model presented in equation 5-6 is correctly specified. However before leaving this topic, one further set of tests will be performed.

Tables 5-3 and 5-4 report the results of running the maintained equation with the addition of variables whose presence has theortical justification. The fact that the coefficients on the included variables are not sensitive to the inclusion or exclusion of these other variables lends support the hypothesis that the maintained equation is correctly specified. Another test of the specification that relies on variable addition is the RESET test (Ramsey, 1969; Anscombe, 1961).

In a RESET test, the higher powers of the predicted values of the dependent variable are added to the right-hand side of the regression equation. These variables can be regarded as a proxy for the true specification (Pagan, 1983). The RESET test is then constructed from an F-test of the null hypothesis that the added variables are insignificant. The power of this test depends on the correlation between the higher powers of the predicted dependent variable and the actual mis-specification, which is, of course, unknown. Some empirical work which has employed RESET (Loeb, 1976; Ramsey and Alexander, 1982; Kramer et al., 1985) find it quite powerful in finding mis-specification in models which fit well under traditional criteria (high R-square values, significant coefficients, theoretically correct signs).

The RESET test was applied to the OLS estimates of the maintained equation using the predicted values of the dependent variable taken to the second, third, and fourth power. This decision was based on evidence by Ramsey and Gilbert (1972) and Thursby (1979) that this is the optimal choice. However, Kramer et al. (1985) conclude that in their study "it did not matter much which test variables from the set of possible candidates were employed for the RESET procedure".

None of the three extra regressors, either taken singly or together, was significant at the 5 percent level. The F-stat for the test of the hypothesis that all three are jointly zero was 1.95 which, with three restrictions and 396 degrees of freedom, is not significant (the hypothesis cannot be rejected). The actual regression results are reported as Table A-5 in the Appendix.

5.7 Summary

In this chapter the production function for university research was estimated. It was found that the research output of an individual faculty member is positively related to that individual's human capital, the average level of departmental human capital, and the number of other faculty members in the department, while being negatively related to the average level of undergraduate, masters, and doctoral level enrolment. A series of nested and non-nested hypothesis tests were performed to determine the functional form which is most consistent with the data, and it was found that one which was nonlinear in the variables is most appropriate. This means that second derivatives and cross-partials are not constrained to be zero. The relevance of this result will be discussed in the next chapter in some detail.

The maintained equation which came out of the model selection process was then subject to a battery of tests designed to test the validity of the stochastic and structural specifications. The results of these tests strongly support the maintained equation. Because of heteroskedasticity in the error term, however, a feasible GLS regression was performed to provide more efficient estimators of the coefficients. It is this result (equation 5-6) which is used to perform the empirical investigations and experiments of the next chapter.

In Chapter 6, each of the three proposed solutions to the funding problem of Ontario's universities will be examined. The implicit nature of the production function which is necessary for each proposal to generate efficiency gains or cost savings will be discussed, and the estimated production function for university research in Departments of Economics will be used to determine what gains, if any, could be realized from implementing the proposals at Ontario's Departments of Economics.

CHAPTER 6

EFFICIENCY GAINS FROM SYSTEM REORGANIZATION

6.1 Introduction

In Chapter 5 the production function for university research was estimated using data from departments of economics at Ontario universities. In this Chapter, the results of that estimation will be used to evaluate the potental efficiency gains or cost savings which would accrue in departments of economics from the application of the policies described in Chapter 1. The three policies; system rationalization, department closures, and input reductions, will each be discussed in turn.

6.2 Proposal #1: System Rationalization

The system rationalization proposal (also known as the two-tier approach) designates two different types of departments in each discipline at Ontario Universities. Tier One departments would specialize in graduate teaching and research, would employ faculty with high levels of research producing human capital and have relatively low enrolment to faculty ratios. Tier Two departments would specialize in undergraduate teaching, would employ low research producing human capital and have relatively high enrolment to faculty ratios. This proposal is predicated on the assumption that the (presumably high) level of research output produced at the Tier One departments, together with the (persumably low) level of research output produced at the Tier Two departments would be greater than the total level of research which would be produced with the same inputs and teaching outputs under the current system. However, in order for this to be true one or more of the following conditions must characterize the production process.

First, the marginal change in any one individual's research output to a change in average departmental human capital should not be zero. If the human capital of other departmental faculty members is not an input into the research output of any one individual faculty member there can be no efficiency gain or loss from the reallocation of existing human capital, cet. par. On the other hand a relationship between one member's research and other members' human capital may (depending on the nature of the relationship) indicate that total (i.e.; province-wide) production of research output could be increased either by increasing or reducing the inter-university disparity of human capital. The former outcome would be consistent with the two-tier approach while the latter would not.

Second, research output and graduate teaching should be jointly produced to at least some degree. If there is no jointness in the production of these two outputs there would be no efficiency gain from having graduate students taught at Tier One universities and undergraduate students taught at Tier Two universities. On the contrary, if the objective is to free up the resources of high human capital faculty members for research it may be more efficient to have graduate students taught at Tier Two universities.(1)

Finally, while the relationship between research output and undergraduate teaching is predicted a priori to be negative, the functional form of the relationship will determine whether total research output would be maximized by increasing or decreasing the inter-university disparity in teaching loads.

With respect to the relationship between the research output of the individual faculty member (RES) and the average level of departmental human capital (DEPHC), the empirical investigation of Chapter 5 clearly confirms the predicted positive relationship. As the average level of departmental human capital rises, cet. par., the research output of any individual faculty member will rise. However, the crucial question is whether a reallocation of existing human capital between departments would alter the total production of research output, and, if so, what allocation of human capital would maximize province-wide research output?

The 'best' specification of production function for individual research output, based on the empirical investigations of Chapter 5, was given in equation 5-6. To simplify the exposition below, the equation

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(1) It may be, however, that the specialization of Tier One departments in graduate teaching as well as research is not based on efficiency arguments, but rather on the argument that the human capital necessary to teach graduate students would only be present in Tier One departments. This study, which assumes teaching services producing human capital is equally present in all faculty members, cannot evaluate this argument.

is presented in equation 6-1 without the estimated values of the coefficients.

$$RESij = a + b1(SIZEj) + b2(SIZE2j) + b3(AVBAj) + b4(AVMAj) + b5(AVPHDj) + b6(HCij*AVPHDj) + b7(HCij*SIZEj) + b8(HCij*DEPHCj) \quad (6\text{-}1)$$

The estimated values of the parameters are given in equation 5-6 in Chapter 5. This equation specifies the production of the research output of the ith individual in the jth department as a function of personal and departmental characteristics. The production function for total departmental research output can be calculated by summing equation 6-1 over i (i=1 . . . SIZEj). The resulting equation is presented below as equation 6-2.

$$\sum_i RESij = a(SIZEj) + b1(SIZE2j) + b2(SIZE3j) + b3(SIZEj*AVBAj) + b4(SIZEj*AVMAj) + b5(SIZEj*AVPHDj) + b6(AVPHDj*\sum_i HCij) + b7(SIZEj*\sum_i HCij) + b8(DEPHCj*\sum_i HCij) \quad (6\text{-}2)$$

In equation 6-2, the total amount of research output produced at department j is specified to be a function of the number of faculty members in the jth department (SIZEj), SIZEj squared and cubed, the total number of students enrolled in programs at each of the three levels (note that AVBAj, etc., equal total enrolment divided by SIZEj), and three interaction terms involving the total level of human capital employed in the jth department ($\sum_i HCij$). Note also that DEPHCj is equal to the sum of HCij, over i, divided by SIZEj. This equation can be written as a production function for the average level of departmental research output by dividing both sides by SIZEj. This yields equation 6-3 below:

$$\begin{aligned} AVRESj &= a + b1(SIZEj) + b2(SIZE2j) + b3(AVBAj) + b4(AVMAj) \\ &+ b5(AVPHDj) + b6(AVPHDj*DEPHCj) + b7(SIZEj*DEPHCj) \\ &+ b8(DEPHC2j) \qquad (6\text{-}3) \end{aligned}$$

As explained in Chapter 4, although all forms of the equation have the same properties, this form provides a convenient way to look at the departmental production function. Finally, to obtain an equation for the total level of research output, province-wide, equation 6-2 can be summed over j (j=1 . . . 15). The result is presented in equation 6-4 below:

$$\begin{aligned} \sum_j \sum_i RESij &= a(\sum_j SIZEj) + b1(\sum_j SIZE2j) + b2(\sum_j SIZE3j) \\ &+ b3(\sum_j (SIZEj*AVBAj)) + b4(\sum_j (SIZEj*AVMAj)) \\ &+ b5(\sum_j (SIZEj*AVPHDj)) + b6(\sum_j (AVPHDj*\sum_i HCij)) \\ &+ b7(\sum_j (SIZEj*\sum_i HCij)) + b8(\sum_j (DEPHCj*\sum_i HCij)) \qquad (6\text{-}4) \end{aligned}$$

In equation 6-4 the left-hand side variable is the total amount of research output produced in the province. It is a function of the total number of faculty members in the province as well as the sum of the square and cube of the number of faculty members in each department. The fourth, fifth and sixth right-hand side terms are simply the total number of students in the province enrolled at each of the three levels; bachelors, masters, and doctoral. The last three terms are interaction terms between the total level of human capital in the department and the per faculty Ph.D. enrolment, number of faculty members, and average level of human capital, respectively, summed over the 15 departments. The last term, it should be noted, can also be written as $(\sum_j(\sum_i HC2ij/SIZEj))$, the sum over departments of the total level of human capital, squared, divided by the number of faculty members.

The information contained in the equations above can now be used to infer what would happen to the total level of research, province-wide, if the existing allocation of human capital was reallocated between departments, while holding total department size and teaching loads constant. If an increase in total, province wide, research output can be obtained by creating some departments with very high average levels of human capital and other departments with very low average levels of human capital, the result would support the system rationalization approach to improving efficiency.

The first step in determining the distribution of human capital that would maximize province-wide research output, holding the levels of enrolment and the number of faculty members in each department constant, and subject to the constraint that total human capital in the province is fixed, is to find the appropriate constrained extremum. This can be done by setting equation 6-4 up as a constrained optimization problem using the standard Lagrangian technique, and finding the appropriate first and second order conditions. This will yield 16 first order conditions:

$$d(\sum_j \sum_i RESij)/d(\sum_i HCij) = b6(AVPHDj) + b7(SIZEj) + 2b8(DEPHCj) + L = 0 \quad (6\text{-}5)$$

$$d(\sum_j \sum_i RESij)/d(L) = \sum_j \sum_i HCij - TOTHC = 0 \quad (6\text{-}6)$$

Where equation 6-5 gives the 15 (j=1 . . . 15) first order conditions derived from differentiating total research output with respect to the level of human capital in the jth department, L is the Lagrangian multiplier, equation 6-6 is the 16th first order condition, derived from differentiating the total level of research output with respect to L, and TOTHC is the total level of human capital in the province. Since b8 is positive (.10626) the second order condition indicates that the constrained extremum found by solving the 16 equations is a minimum, rather than a maximum.(1)

This result implies that the solution to the maximization problem is a corner solution. That is, it occurs when all human capital is in one department. This is neither a feasible solution given the actual distribution of human capital across individual faculty, nor is it a reasonable view of what a rationalized system would look like. For this reason the potential efficiency gains which might be realized from

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(1) Solving this system for L and the 15 values of ($\sum_i HCij$), and then substituting these 15 values into equation 6-4, along with observed values of all other right-hand side variables, produces an estimate of the level of research output that would be generated by the least efficient allocation of human capital. Performing this operation indicates that the minimum is achieved by a more equal distribution of average human capital. This extremum would reduce overall research output by 6.23 percent.

system rationalization will be inferred from a series of experiments in which the existing amount of human capital is reallocated across existing departments, cet. par., in ways that are possible, given the actual distribution of that human capital.

The first set of experiments involves the assumption that the existing faculty members will be moved between departments to reallocate the total amount of human capital in the province while holding SIZE, AVBA, AVMA, and AVPHD constant at each institution. For the first experiment (E-1) two tiers of universities are created.(1) The Tier One departments consisted of Carleton, McMaster, Queen's, Toronto, and Western, each of which were left with the same total number of faculty members and enrolment by level, but with an average level of human capital (DEPHC) of 3.11728. The remaining 10 universities (Tier Two) were also left with their original number of faculty members and enrolment but with an average DEPHC of 0.5. The latter number was chosen arbitrarily, partly to prevent the predicted value of RES from being negative for any individual department, and partly to keep the experiment within the range of actual observations. Given this assumed value, and the total number of individuals who are employed at Tier Two departments, the amount of human capital left for the Tier One

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(1) The choice of Tier One and Tier Two departments is entirely arbitrary. This analysis is concerned only with comparing production under hypothetical alternative systems and not with the costs of transforming the status quo into any other system. Thus, Tier One departments could, on paper, just as easily be created at Trent or Laurentian, as at the University of Toronto or Queen's.

departments was then calculated. Dividing this number by the total number of faculty employed at these departments yielded the value 3.11728. This too is within the range of actual observations (the range of observed levels of DEPHCj is from 0.30 to 3.35). As a result of this hypothetical reallocation, total province-wide research output is predicted to increase by 6.79 percent over the status quo with the 47.52 percent fall in production from the 10 Tier Two universities more than made up for by an increase of 19.84 percent in the production of the five Tier One universities. (Note that all calculations are taken with respect to the predicted values of departmental research output rather than observed values. In the case of province-wide research output the two values will only differ by rounding error since the LS estimation technique constrains the sum of the predicted values of the dependent variable to equal the sum of the observed values.)

This result (of fairly modest efficiency gains) is determined by the decision to create 5 Tier One universities, and to keep the average levels of human capital at both Tier One and Tier Two departments within the range of observed values. Obviously, the more unequally distributed the human capital, the greater the efficiency gains. To illustrate this point a series of three-tier system were investigated. In each case, the 10 Tier Two departments were maintained as in the first experiment. However, in these experiments one Tier One department is given more average human capital than the other four. The University of Toronto was chosen since it is the largest department.(1) No experiment is performed that involves a distribution of human capital which cannot be accommodated by the observed distribution. This constraint is not too limiting since the observed distribution is heavily skewed. The top 21 percent of faculty account for 71 percent of human capital while the bottom 59 percent of faculty account for only 9 percent of human capital. (See Table A-6 in the Appendix).

Three such experiments (E-2, E-3, and E-4) will be performed. For E-2, the university of Toronto will be given 1.5 times the level of human capital it has under the status quo. Thus DEPHCj for the University of Toronto becomes 4.185. DEPHCj for the remaining 4 Tier One departments is then residually determined as 2.5066. The experiments E-3 and E-4 involve the same procedure but with the University of Toronto having 2 and 2.5 times current levels of human capital respectively (5.58 and 6.975), and the other four departments' levels caluclated accordingly (1.7095 and 0.9123).

A better understanding of the impact of these experiments can be gained from an examination of Table 6-1 below. Table 6-1 gives the total expected research output for each of the five Tier One universities and the other ten universities taken together (Tier Two)

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(1) Of course, the maximum efficiency gains would be created by altering the sizes of departments, as well as their average levels of human capital. This is considered in a later section. However, at this stage no presumption can be made that if a three-tier, or superdepartment, system is created, the superdepartment would necessarily be the largest.

for each experiment (E-1 to E-4) and for the existing distribution of human capital (BASE). Note that BASE is predicted research output given observed values of independent variables, not observed research output. This is the appropriate basis of comparison.

TABLE 6-1: Potential Efficiency Gains from A Two Tier System

University	E-1	E-2	E-3	E-4	BASE
Tier Two	30.59	30.59	30.59	30.59	63.44
Carleton	34.67	26.28	18.67	14.84	31.33
McMaster	36.41	27.84	20.22	16.66	25.92
Queen's	40.20	31.53	24.63	22.72	34.44
Toronto	76.29	130.05	232.38	371.12	64.05
Western	103.69	82.44	61.72	48.98	82.23
Total	321.85	328.76	388.25	504.95	301.41

All of the experiments reported in Table 6-1 are highly artificial in the sense that the existing size and teaching load of each department has been left untouched, while only the distribution of human capital amongst the departments was changed, although care was taken to ensure the reallocation of human capital was feasible. The universities chosen to have Tier One departments were, while not entirely arbitrary (the five Tier One departments have the five largest values of AVPHDj, and the superdepartment chosen for E-2 to E-4 has the largest value of SIZEj), not made on the basis of any overall optimization criterion. The purpose of this investigation is to determine the degree to which efficiency gains from system reorganization would result from the reorganization of human capital alone, without reference to the gains that might be realized from altering the size of various departments or the allocation of students among them.

The conclusion that can be drawn from this investigation is as follows. The estimated form of the production function supports the notion, implicit in the system rationalization proposal, that increased output would be generated by placing the high human capital faculty in Tier One departments, and low human captal faculty in Tier Two departments. This would occur even if no other changes were made to the system. However, the degree of increased output so generated depends greatly on the degree to which the alternative system diverges from the status quo. E-1, which involves a fairly major redistribution of faculty, generates an efficiency gain of less than 7 percent. E-4, on the other hand, generates an efficiency gain of 67.4 percent. This is a very substantial gain, but it must be regarded with some caution since it involves a value for DEPHCj which lies well outside the range of observations. While it is always dangerous to predict outside the range of observations, it is particularly so when using a value twice as large as the largest observation. As well the substantial efficiency gains of E-2 to E-4 involve a degree of human capital reallocation that can only be described as radical.

The preceeding analysis has indicated that a reallocation of human capital amongst departments, along the lines indicated by system rationalization, would improve efficiency, although it seems doubtful that major efficiency gains could be generated by this method alone. A second aspect of the system rationalization proposal involves the specialization of individual departments in either undergraduate teaching or graduate teaching and research. If the grouping of graduate teaching with research is to improve efficiency, it is necessary that some jointness in production of research and graduate, or at least doctoral, teaching exist. If some jointness does exist, then concentrating the human capital (and reducing the undergraduate teaching obligations) in departments which have graduate programs should increase the marginal productivity of human capital in the production of research output. If there is no jointness, and graduate teaching is not jointly produced with research then it makes no sense to have graduate students taught at Tier One Universities.

There are two ways the presence of doctoral candidates in a departments might influence the amount of research produced. The first is that, cet. par., more students at any level use up resources which might otherwise go into the production of research. Since teaching doctoral candidates is likely to require more faculty resources, on a per student basis, than does teaching undergraduates, it might even be supposed that the presence of doctoral candidates would have a relatively large negative effect on research. On the other hand, the presence of doctoral students to act as teaching and research assistants, and the fact that time spent preparing graduate level lectures may also act as an input into research, implies a postive influence of doctoral students on research. There are two ways to attempt to measure this influence. The first is simply to calculate the marginal change in average research output of a department due to an increase in the per faculty level of doctoral candidates. If this is positive, it might be argued that the positive effects outweigh the negative effects. Caluclating this partial derivative from equation 6-2 yields:

$$d(AVRESj)/d(AVPHDj) = b5 + b6(DEPHCj) \quad (6\text{-}7)$$

Using the estimated values of b5 and b6 (.15831 and -.21476, respectively), and evaluating at the means gives a numberical result of -.1364. It should be noted that this result is not highly sensitive to the particular functional or stochastic specification employed in the regression. This marginal is negative for every one of the 17 different regression equations reported in Chapter 5 except one (the TOBIT regression in Table 5-2). However, since b5 is not significantly greater than zero while b6 is significantly negative in that regression, it cannot properly be regarded as a contrary example.

The second approach to evaluating the influence of doctoral candidates on research is to evaluate the cross partial derivative that represents the change in the marginal product of human capital in the production of research output from an increase in the per faculty level of doctoral enrolment. This is simply b6, which is significantly negative.

These two results indicate that as the per faculty enrolment of doctoral candidates rises in any given department, the average level of research output falls, and the productivity of human capital in the production of research falls. It should be noted that the form of the production function implies that if the existing stock of doctoral students were to be disturbed so that the number of doctoral students at low human capital departments fell and the number at high human capital departments rose, _cet. par._, the total amount of research produced, province-wide, would fall. In fact, based on the estimation of the production function, it would appear that maximum output would occur where doctoral students are taught in departments with very low average levels of human capital. However, this interpretation is not appropriate since it involves predicting well outside the range of observations (the vast majority of doctoral candidates are now enrolled in departments with above average levels of human capital).

It thus appears that what ever jointness exists in the production of doctoral teaching and research, it is not to suggest that efficiency gains might be realized from causing Tier One departments to specialize in both. If anything, the contrary is indicated. It must be concluded, then, that the argument for having graduate students in general, and doctoral candidates in particular, enrolled in Tier One departments can only be supported by the argument that research producing human capital is a necessary input into the production of graduate teaching. The argument that research productivity is increased by such an arrangement is not supported by the data.

The final issue to be dealt with concerns the role of undergraduate teaching in the system rationalization proposal. The two tier approach suggests that undergraduate teaching loads at Tier One departments should be reduced to allow the high human capital researchers more time to produce research, while at Tier Two departments the undergraduate teaching load should rise. While this suggestion is appealing, there is no evidence from the estimated form of the production function to support it. The estimated value of b3 is negative (-.015159) and significant (t-statistic = 2.394). This means that as the average undergraduate teaching load at any university rises, cet. par., average research output falls. However, the form of the production function implies that a reallocation of students between departments will have no effect on overall research output. This result is surprising, and it might be argued that functional forms which support the two tier approach in this regard have not been properly tested against the maintained hypothesis. In fact, when the equation is estimated allowing interaction terms between AVBA and HC, and allowing AVBA squared terms, the same result emerges. (These regressions are reported in Table A-2 and Table A-3 in the Appendix). While lowering the ratio of students to faculty in the province as a whole will increase research productivity, redistributing undergraduate teaching loads does not seem to make any difference.

Conclusion:

Although the notion of a two-tier university system for Ontario is appealing, it rests on several implicit assumptions about the nature of academic production. Specifically it is assumed that total university production would be increased if high human capital researchers were congregated together in research-oriented departments, if graduate teaching and research were jointly produced, and if the undergraduate teaching load were shifted away from the high human capital faculty and to the low human capital faculty. However the evidence from departments of economics suggests that very little increase in production, if any, could be expected from such an approach. There is really no evidence at all that graduate teaching and research are jointly produced or that shifting the undergraduate student population in that way would increase efficiency. On the contrary, evidence suggests that graduate student teaching takes more resources away from research than does undergraduate teaching and that the allocation of undergraduate students across departments is irrelevant. While there is some evidence that efficiency gains (and thus potential for cost savings) could be realized from a reallocation of human capital, it appears that very major changes in the nature of the university system would be needed to create significant efficiency gains.

Moreover, this section has only investigated the potential increase in efficiency which might result from having in place a 'rationalized' system rather than the existing system. It has not focused on two issues which would need to be addressed if the university system in Ontario was actually going to be 'rationalized'. The first is the question of whether the quality of undergraduate education could be maintained in Tier Two departments, and whether these departments would be capable of providing service teaching to other departments within the university. This study assumes that teaching outputs are homogenous and thus cannot address this issue directly, except to note that had the results of the analysis indicated substantial potential efficiency gains from system rationalization, a cautionary note would have to be sounded on this account. The second issue which would have to be dealt with if system rationalization were to be implimented is the costs of system transformation. This too is beyond the scope to this study. However, it might be noted that the costs of transforming the system in the way described here cannot be assumed to be insignificant. Indeed, they may be substantial. This too strengthens the conclusion that as a way of cutting costs by improving efficiency, rationalization, at least in Departments of Economics, is unlikely to be effective.

Finally, it should be noted that this section is predicated on the notion that system rationalization is conceived of as a method of cutting costs by improving efficiency, and thus being able to provide the same levels of outputs with fewer inputs. However, it is also possible to view the system rationalization proposal as a way in which to organize the eventual reduction in outputs so as to maximize the cost savings per output forgone. This notion will be pursued further in a later section of this chapter.

6.3 Proposal #2: Department Closures

The second proposal is conceptually far more straight forward. This proposal simply argues that one or more small departments should be allowed to close and that the students should be absorbed by the remaining institutions. If there are economies of scale in university production, and if some existing departments are below optimal size, then the existing level of production could be achieved with fewer inputs. In this section the potential efficiency gains which could be realized from reducing the number of Departments of Economics will be investigated.

In Chapter 5 a large number of specifications were investigated in order to find the 'best' specification of the production function for the research output of individual faculty members. In every case the results show a positive relationship between the research output of any faculty member and the number of faculty members in the department, cet. par., up to a limit. These results, which were very stable over different specifications, clearly indicate that economies of scale exist in university production, at least over some range of of production. This result is not surprising. We would expect that in larger departments faculty members would be more likely to find colleagues who work in the same general area of research and thus who could provide input into each other's research.

The exact nature of the scale economies can be clearly seen from equation 6-3 in which the function for the average level of departmental research output is inferred from the form of the estimated production function. In that equation all right-hand side variables except SIZEj are per faculty averages. Thus if total levels of human capital, number of faculty, and total enrolment by level were to (say) double, the only variable which would change would be SIZEj. Thus d(AVRESj)/d(SIZEj) directly gives a measure of economies of scale. This partial is presented below:

$$d(AVRESj)/d(SIZEj) = .0324 - .00061(SIZEj) + .0023(DEPHCj) \quad (6\text{-}8)$$

Setting equation 6-8 equal to zero, and solving for the optimal department size yields the equation:

$$SIZEj = 53.115 + 3.77(DEPHCj) \quad (6\text{-}9)$$

Equation 6-9 indicates, for any given department, the number of faculty members that would maximize average research output, assuming that the department's average levels of enrolment and human capital remain unchanged. Since that number cannot be less than 53.115, most departments would have to grow in size in order to achieve their optimum. Evaluated at the mean value of DEPHCj, this gives a numerical solution of 59.37. Thus if every department of Economics in the province had the same average level of human capital, and each were to change in size, while holding the average levels of enrolment and human capital constant in the process, each would achieve its maximum level of average research output when it had 59.37 faculty members. This, of course, would not preserve the province-wide totals at their status quo levels. However, another way of looking at the implications of equation 6-9 is to note that if the entire system was restructured so that it consisted of a number of identical departments, and so that existing province-wide enrolment, human captial, and faculty totals were preserved, the optimal number of faculty members for each of the identical departments would be 59.37.

The fact that all departments but two are substantially below the calculated value of optimal department size indicates that some caution should be used when interpreting this result. The data clearly show economies of scale which diminish as departments increase in size. This is reflected in the highly significant estimated coefficients of b1 and b2 (.032383 and -.000304, respectively). Using a quadratic form forces the results to produce an extremum, even though there are not enough observations past the extrmeum to allow the inference that departments larger than the optimum are becoming less productive as they grow in size. It is more appropriate to regard the extremum as a minimum efficient scale.

As mentioned above, some care must be taken when trying to derive numerical results from a regression equation outside the data region. For that reason the result that the optimal size for a department of economics is between 59 and 60 members should be regarded with caution. However, as a preliminary experiment the regression results reported in Chapter 5 can be used to estimate the potential increase in research output that would be available if the system was completely reorganized so as to take advantage of the minimum efficient scale. Two preliminary experiments will be performed to determine the outside limit of potential increases in output resulting from altering department sizes. The first experiment will be to create five departments with 58 faculty members and 2 with 59 members, each of which will have equal average levels of human capital and enrolment by level, which will, when aggregated across the departments, be equal to the provincial totals in the status quo. The result of this experiment is that the total amount of research output increases by 40.06 percent. This is not a ceteris paribus experiment with respect to the status quo since it involves hypothetical values for all departmental attributes, and not only for SIZE. In fact, by equating the value of DEPHC in all departments, this experiment has effectively minimized the potential increase in output available as a result of having fewer, larger, departments. The potential efficiency gain will increase as the human capital becomes less equally distributed, as in a two-tier system. To illustrate this, a second experiment was performed in which the two departments with 59 faculty members were designated Tier One departments, and allocated an average level of human capital equal to 3.5 (which is slightly above the maximum observed value). The remaining 4 departments, which have 57 faculty members each, were allocated 1.4631 units of DEPHC, residually. This experiment generates an increase in production of 59.89 percent.

The results of these two experiments clearly reveal that, based on the regression results of Chapter 5, very substantial gains can be made in output through moving towards optimal department size. Further, unlike the experiments reported in Table 6-1, it was not necessary to predict outside the range of observations in order to generate very large production gains.

While these are interesting experiments in that they give the maximum possible increase in production, they are not really the relevant experiments for two reasons. First, more than the closure of one or more small departments, they represent the total reorganization of the whole university system. Second, these experiments only focus on the increased output side of the result, rather than on the potential manpower savings which might be realized. For these reasons several additional experiments will be performed. The approach followed in these experiments will be as follows: Several small departments will be assumed closed and their students will be allocated to the remaining departments on a pro rata basis. This will have the effect both of lowering overall research output and lowering the total number of faculty members employed in the province. However, by closing departments which are well below optimal size the overall university sector should become more efficient. These efficiency gains could be exploited to reestablish some research output goal without re-hiring all released faculty.

For this experiment it will be assumed that four departments will be closed, Brock, Laurentian, Trent and Wilfrid Laurier. These were chosen solely on the grounds that none have a graduate program of any kind (thus simplifying the calculations) and because they are all well below optimum size.

To begin with it should be noted that while the four closed departments contain within them 10.54 percent of faculty they produce 11.59 percent of the undergraduate teaching output and 2.9 percent of the research output. Thus, for the first experiment if these four departments were allowed to close and no new faculty were hired at the remaining 11 departments, there would be a fall in total research output of only 6.4 percent, of which 2.9 percent would represent the lost output of the released faculty members and 3.5 percent would represent the fall in research output of the remaining faculty members due to the increase in undergraduate teaching.

One of the implications of the above experiment is that not only will overall research output fall, but so too will total research output at each remaining department. A second experiment, then, would be to have each remaining department hire back enough faculty to maintain the average level of research output (AVRESj) constant at the remaining departments. For this experiment it will be assumed that the newly hired faculty will possess the same average level of human captial as that at the hiring department.(1)

To calculate the increase in SIZE needed at each remaining department to accommodate the increased undergraduate enrolment while holding average research output per department, average human capital, and total graduate enrolment constant it is necessary to rewrite equation 6-3 as equation 6-10 below:

$$\begin{aligned} AVRESj = a &+ b1(SIZEj) + b2(SIZE2j) + b3(ENRBAj/SIZEj) \\ &+ b4(ENRMAj/SIZEj) + b5(ENRPHDj/SIZEj) \\ &+ b6((ENRPHDj/SIZEj)*DEPHCj) + b7(SIZEj*DEPHCj) \\ &+ b8(DEPHC2j) \end{aligned} \qquad (6\text{-}10)$$

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(1) If the number of faculty members required at the hiring departments is large, it is possible than not enough high human capital faculty members can be found among those released. However, the number of rehired faculty turns out to be sufficiently low, so that it would be possible to maintain DEPHC constant at the hiring departments.

Taking the total differential of equation 6-9, setting d(AVRESj), d(ENRMAj), d(ENRPHDj), and d(DEPHCj) equal to zero, and collecting terms, yeilds equation 6-11:

$$d(SIZEj)/d(ENRBAj) = -b3/[b1(SIZEj) + 2b2(SIZE2j) - b3(AVBAj) - b4(AVMAj) - b5(AVPHD) - b6(AVPHDj*DEPHCj) + b7(SIZEj*DEPHCj)] \quad (6\text{-}11)$$

This equation can then be evaluated for each of the 11 remaining departments and multiplied by the required increase in ENRBA to obtain the needed increase in SIZE at each remaining department which, when summed will give the total new faculty requirements at the remaining 11 departments required to accomodate the students freed up by the closure of the the four mentioned. This procedure generates the result that the remaining departments would have to increase in their faculty inputs by an amount equal to 1.99 percent of the province-wide <u>status quo</u> level in order to accommodate the extra undergraduate students without lowering their average level of research output.(1) This would mean that province-wide manpower reductions would be in the order of 8.76 percent rather than the 10.54 percent reduction that would occur if no new faculty were allocated to the remaining departments.

While the previous experiment was designed so that the average

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(1) In this procedure, the actual level of research output at the remaining departments will rise since it is the per faculty average which is returned to its prior level, and faculty size has increased.

amount of research produced at the remaining 11 departments was held to the level actually attained in the base year (the status quo level), the total amount of research produced province-wide would still be less than it was under the status quo. In order to determine the extent to which inputs could be reduced through department closures while still holding outputs constant a third and final experiment will be undertaken. In this experiment it will be assumed that the objective is to maintain total provincial output of research constant at its status quo level. Each department will be assumed to increase in size by a constant percentage and to hire new faculty with average levels of human capital equal to the departmental average. Using numerical techniques, it was determined that the remaining departments would have to increase faculty inputs by 7.35 in order to accommodate the extra undergraduate enrolment without lowering overall provincial output of research output. This means that overall manpower savings from closing the four departments would be only 3.96 percent. This represents the potential manpower savings assuming no loss of output was to occur. The results of these three experiments are summarized in Table 6-2.

It should be noted that the dollar value of savings that could be realized from these experiments are somewhat overstated by the manpower savings since it is assumed that the rehired faculty have the same average human capital as the hiring departments, while the average human capital at the closed departments was below provincial average. Thus the human capital of the faculty not rehired will be well below provincial average.

TABLE 6-2: Potential Efficiency Gains from Department Closures

Experiment	Reduction in Manpower Requirements	Reduction in Research Output
1	10.54%	6.40%
2	8.76%	3.04%
3	3.96%	0.0%

Conclusion

The various experiments performed in this section, while entirely hypothetical and speculative, do give a clear indication of the extent to which faculty manpower could be reduced or research productivity increased through closing some departments and reallocating resources and students to the remaining institutions. There are clearly economies of scale in the production of research output in Departments of Economics. For any given level of average departmental human human capital larger departments (up to a limit) are more productive on average than smaller departments. However the degree to which the university system as a whole could realize actual savings from system reorganization depends on several factors. The experiment of closing several small departments and reallocating their students to the remaining departments on a <u>pro rata</u> basis, which in a realistic context is a very radical solution, turns out to have a very limited potential for reducing the required levels of inputs while still producing the same level of outputs. This result occurs because although the closed departments are well below optimal size, the remaining institutions move only marginally closer to the optimum. In order fully to realize the potential productivity gains in research output from university closures it appears that a much more radical alteration to the existing structure of the university system is indicated.

In addition, the solution of closing a given department in any one university may be impractical except in the case of specialized professional departments (such as architecture). In the case of economics, which performs service teaching for other departments, it is unlikely that a university could close down the whole department and still function as a full university. Simply reducing the scale of operations rather than totally closing the department would reduce even further the manpower savings indicated in the previous section. On the other hand, since there is no indication that all departments are subject to the same scale economies as is the department of economics, it is not clear that these manpower savings could be realized across the system if entire universities were closed.

6.4 Proposal #3: Input Reduction

The final proposal is significantly different from the previous two. While the first two proposed solutions involved reorganizing the university system so that the same levels of outputs could be more efficiently produced, the third solution simply involves reducing the levels of inputs into the production process and accepting the resulting reduction in outputs. It is obvious that a reduction of inputs would reduce costs, and the standard production model on which the analysis has been based (and which has been supported by the data) implies that a reduction in inputs will cause a reduction in outputs. The only questions which remain concern which inputs, which outputs, and the degree to which reduction in the former will reduce the latter.

In this section several simple hypothetical experiments will be performed, using the basic model estimated for Departments of Economics, in an attempt to deal with these questions. There are a number of ways in which the total level of inputs in the university system could be reduced and a number of ways these reductions could be allowed to affect the provision of outputs. On the inputs side the two areas for reduction are either the number of faculty members (SIZE) or their average levels of human capital (DEPHC). The former could be reduced explicitly 1) by eliminating departments (through university closures) and holding other departments at the same size, 2) by simply causing a reduction in the number of faculty in each department, or 3) implicitly by allowing the total number of students to rise over time with no corresponding increase in faculty members. The latter could be reduced by placing a maximum on faculty salaries, thus allowing faculty with high human capital to move to other jurisdictions, and preventing the inflow of high human capital faculty from other jurisdictions. On the outputs side, the number of students who will be serviced by the university system can simply be set and this level, taken together with the reduced levels of inputs, will residually determine the amount of research produced.

Some of the issues raised above can be investigated quite simply through an examination of equation 5-6. For example, the estimated coefficient on AVBA in that equation is -.01516. This gives the change in average research output for a one unit change in average undergraduate enrolment. More to the point, it can be seen from equation 6-4 that this coefficient represents $d(\sum_j\sum_i RESij)/d(SIZEj*AVBAj)$, which is the change in the total level of research output, province-wide, for a marginal increase in total undergraduate enrolment, province-wide. A one percent rise in total undergraduate enrolment in Departments of Economics (59.2725 students) would lower total research by only .8985 units, which is only a .2981 percent fall. Similarly a 10 percent rise in enrolment would lower research output by just less than 3 percent.

TABLE 6-3

Percentage Reduction in $\sum_j\sum_i RESij$ Resulting from Input Reductions

Input Variable Reduced	Percent Reduction: 5	10	15	20
SIZE	6.04	12.42	19.02	25.79
DEPHC	4.93	9.86	14.79	19.71
SIZE & DEPHC	10.74	21.29	31.59	41.57

An alternate approach would be to assume a proportional reduction in SIZE and the total level of human capital ($\sum_i HCij$) at each existing department and, holding enrolment at all levels constant, calculate the resulting reduction in research output. The reduction in

($\sum_j\sum_i$RESij) that would result from such input reductions is given in Table 6-3 above.

The first row in Table 6-3 presents the percentage reduction in total research output province-wide that would result from increasingly large reductions in SIZE holding DEPHC constant at its status quo level. Thus a ten percent reduction in SIZE would represent a ten percent reduction in total faculty input costs since the released faculty have average characteristics. It should be noted that because of the non-linear functional form of equation 5-6, with respect to SIZE, the loss in research output for a loss in SIZE grows as the reductions become larger and the departments move further away from their optimal sizes. The second row represents the percentage reduction in researach output that would result from increasingly large reductions in average human capital (DEPHC), while holding department size constant at its status quo level. Because of the non-linear relationship between total research output and average departmental human capital, the percentage loss in research output grows as DEPHC gets smaller. Finally, the third row gives the reduction in research output which would result from increasingly large reductions in both the number of faculty at departments and their average human capital.

We can note that the effect of reducing the number of faculty members and at the same time reducing the number of undergraduates enrolled in the system has already been investigated to some extent. In a previous section it was discovered that if four universities were closed (Brock, Laurentian, Trent, and Wilfrid Laurier) and the other universities did not increase enrolment the loss in province-wide undergraduate enrolment in Departments of Economics would be 11.59 percent, the reduction in faculty members would be 10.54 percent, and there would be a 2.9 percent reduction in research output.

Conclusion

The final proposal which was investigated involved reducing inputs in the university system and identifying the loss in outputs thereby generated. This approach will certainly work, the only question is how great will be the resulting loss in outputs. Of particular interest is the loss in research output that would result from input reduction while holding enrolment levels constant. Analysis of these issues indicates that: a) a ten percent increase in undergraduate enrolment in economics with no corresponding increase in inputs would result in a 2.01 percent fall in research output; b) a 10 percent reduction in faculty with no corresponding decrease in enrolment at any level would reduce research output by 12.42 percent; c) a ten percent reduction in average human capital with no reduction in enrolment would reduce research output by 9.86 percent; d) a ten percent reduction in both the size and average human capital of faculty without any reduction in enrolment would cause a 21.29 percent reduction in research output; and e) the closure of small departments of economics at four universities, with no provision made for increasing the inputs or teaching outputs at the remaining departments would result in a fall in total undergraduate enrolment of 10.54 percent and in research output of 2.9 percent.

6.5 Summary

In this chapter the basic production model of Chapters 3 and 4 (which was estimated in Chapter 5) was interpreted as a function for the production of research on a departmental and provincial basis. Each of three proposed solutions to the funding problems of Ontario's universities was examined on the basis of the estimation results.

Of the three proposals, the reduction of inputs would be effective in reducing cost regardless of the nature of the production process. The estimation supports the production function model and indicates that a reduction in inputs will result in lower production of outputs, although the exact loss in production will depend on the way in which inputs are reduced.

The other two proposals do depend on some implicit assumptions about the nature of academic production. It was determined that the evidence supports the hypothesis that efficiency gains would be realized from both (or either) proposal. However, the efficiency gains in both cases seem very modest for all but the most radical surgery to the existing system. In the case of system rationalization, significant efficiency gains cannot be generated within the range of actual observations, and gains seen outside the range of observations must be regarded with extreme caution.

There are several points about the analysis in this chapter which should be noted. First, the statistical model used in the study incorporates the assumption that the quality of teaching output would be invariant with respect to changes in the organization of production. Second, it ignores any savings which might result from the proposals outside the area of efficiency gains. These two issues are examined in Chapter 8. Third, it uses data from one department only. There is no indication that Economics is representative of all social science disciplines. Other disciplines may be very different. (In fact, evidence from Departments of Political Science and Sociology, presented in Chapter 7, suggests other disciplines are very different.) Finally, the estimations of Chapter 5, which have been used in this chapter are based on a series of data definitions and aggregation procedures which may have had a major role in determining the outcome. These last two issues are examined in Chapter 7.

CHAPTER 7

SENSITIVITY ANALYSIS

7.1 Introduction

In Chapter 5 a model of academic production was estimated for academics working in Departments of Economics. The data used for the estimation was created using certain definitions, procedures and conventions. The result was a strong set of regressions in which estimated coefficients took on the expected signs and were generally significantly different from zero. The basic production model was supported by the data, and definite economies of scale were identified. While the evidence did support the hypothesis that either of the first two policies (system rationalization and department closures) would improve efficiency, there is no evidence to suggest that anything short of a radical reorganization of the entire university system would generate significant improvements in the efficiency of production in Departments of Economics.

In this chapter the stability of the results presented in Chapter 5 will be examined. Three questions are of particular interest and importance. First, are the results applicable only to Departments of Economics or can these results be generalized to other discliplines? Second, are the results for Departments of Economics stable under alternative objective definitions of outputs? Finally, are the specific results obtained sensitive to the use of other aggregation procedures?

These are important questions. With respect to the stability of the results across disciplines, there was an a priori presumption that each discipline needed to be investigated individually. It was for that reason that the study was conducted using only elements drawn from one discipline. It is possible that the measure of research output chosen for one discipline might be quite inappropriate for another. Further, even if one measure could be found that would function as a proxy for research output in more than one discipline, the process of production may be qualitatively different, and may imply different right-hand side variables. Finally, it would certainly be expected that even if a common left-hand side variable could be found, and if the production process was common, the quantitative results would differ between disciplines. However there may be some some aspects of the production relationship (e.g., economies of scale) which do hold across disciplines, or at least across disciplines within a given area (social sciences, physical sciences, etc.). Whether the presumption of significant differences between disciplines is supported or rejected by the data is of some importance to the basic problem at hand because some of the proposals concerning the future oraganization of the university system in Ontario would require similar reorganizations of all disciplines (or at least all disciplines in a given area) while others could be applied on a discipline-by-discipline basis. Thus, for example, if the examination of different disciplines indicates that increasing returns to scale such as those found for Economics generalize to other disciplines, then the solution of creating fewer, larger universities would create efficiencies in all departments. If, on the other hand, it seems that many disciplines are not characterized by increasing returns to scale then the potential efficiency gains from university closures would be much more limited.

Regardless of whether the production process in Departments of economics is unique or similar to that in other departments there also remains the crucial question of whether the results for Departments of Economics are insensitive to the operational definitions of outputs chosen or whether alternate definitions would significantly change the results. This question is particularly important because the definitions of outputs are so problematic. This is especially the case for the specific publication-based measure of research output which is used in the study. A number of other measures have been suggested or used in the literature (the most prominent of which are articles weighted by quality of journal and by page length) and it is important to find out whether the results of Chapter 5 are sensitive to the specific measure chosen. In addition, the student-based measure of teaching output, although far more standard in the literature, can also be measured in different ways. Further, as discussed in Chapter 2, it is not really possible to determine on theoretical grounds which of the many possible definitions is preferred. If the choice of objective definition vastly alters the results of the analysis, serious doubt is cast on the validity of all existing university production studies. Indeed it might be argued in that case, that given the current state of knowledge about the definition and measurement of university outputs, no production study is possible. This would be a very unfortunate result given the obvious need for studies of this type to form the basis of an intellegent debate on the issues concerning university financing.

In order to make the data usable, certain aggregation conventions were employed. If the specific results of the analysis are highly sensitive to the conventions, serious doubts are cast about the validity of the results and the applicability of the conclusions.

In the remainder of this chapter, analysis pertaining to the sensitivity of the results will be performed. In Chapter 8 the implications of the analysis performed in Chapters 5, 6, and 7 for the evaluation of the future organization of the university system in Ontario will be discussed.

7.2 Stability Across Disciplines

In Chapter 3 it was explicitly recognized that in different disciplines the production of academic outputs would face different constraints (production functions). However, as explained above, it is useful to know the degree to which the estimated production function would differ across disciplines. It seems likely that the production function for experimental sciences such as Biology would be vastly different from that for Economics. Experimental disciplines require far more in the way of equipment and physical space than does Economics. The relationship between graduate students and research is also quite different. In addition, in many non-experimental disciplines, such as History, the publication of books takes on far more value as research output, and the publication of journal articles far less, than is the case in Economics. For these reasons it is highly unlikely that a production function which used the same data definitions and the same specification as the production function for Economics would be found to fit the data well for other disciplines. Of all other disciplines taught in the universities, the ones which would seem to be most like Economics, and thus most likely to share production characteristics, are those in the social sciences. Accordingly, two other disciplines in the Social Sciences were chosen for analysis. These two disciplines are Sociology and Political Science. The other two traditional social sciences, Psychology and Geography, were explicity ruled out because at many universities these disciplines are laboratory or physical sciences and thus quite unlike Economics. In the case of both of Sociology and Political Science, it is likely that some problem will arise with the measure of research output because of the higher prestige attached to book publication. However, the choice of these two disciplines has the advantage that, to the extent that article publication is undertaken, these articles are fully surveyed in the SSCI and thus the same data definitions that were employed in Chapter 5 can be used here. This will greatly facilitate direct comparison of the results.

The basic model of Chapter 5 is thus re-estimated for the disciplines of Political Science and Sociology and the results are reported in Table 7-1 (Political Science) and Table 7-2 (Sociology). The dependent variable is again research output (RESij) and in both tables the same set of four specifications are estimated and reported.

TABLE 7-1: OLS Estimation of the Production Function with Political Science Data

Variables	Regressions 1	2	3	4
HC	.200060 (2.362)		.120030 (2.381)	.154780 (6.120)
HC2	.018377 (1.996)		.005704 (0.795)	
DEPHC	-.054502 (-0.163)		.140040 (0.414)	-.059304 (-0.762)
DEPHC2	.033133 (0.344)		-.056987 (-0.615)	
SIZE	-.002702 (-0.166)	-.003101 (-0.196)	.000726 (0.043)	-.001282 (-0.079)
SIZE2	-.000021 (-0.106)	-.000060 (-0.299)	.000012 (0.055)	.000032 (0.158)
AVBA	-.006347 (-1.246)	-.005672 (-1.103)	-.006129 (-1.168)	-.006057 (-1.156)
AVMA	.025024 (1.001)	.020360 (0.844)	.021042 (0.819)	.024179 (0.977)
AVPHD	.143930 (0.848)	.12321 (0.904)	-.135320 (-0.855)	-.085309 (-0.669)
HC*AVPHD	-.210630 (-3.906)	-.208490 (-3.868)		
HC*SIZE	.004605 (2.216)	.008669 (5.317)		
HC*DEPHC	-.101360 (-2.405)	.004906 (0.316)		
INTER-CEPT	.261110 (0.795)	.315450 (1.405)	.191360 (0.567)	.308680 (1.237)
R-SQUARE	.1851	.1514	.1260	.1233
F-STAT	5.583	6.667	4.774	6.028
RSS	144.15	150.11	154.59	155.07
d.f.	295	299	298	300
SEE	.69903	.70854	.72026	.71896

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE 7-2: OLS Estimation of the Production Function with Sociology Data

Variables	Regressions			
	1	2	3	4
HC	-.003756 (-0.520)		.186660 (5.680)	.159190 (9.165)
HC2	-.005184 (-1.833)		-.002210 (-0.985)	
DEPHC	-.023341 (-0.163)		-.133890 (-0.345)	.178390 (2.620)
DEPHC2	.051450 (0.474)		.086342 (0.803)	
SIZE	.013540 (0.807)	.024665 (1.675)	.006447 (0.384)	.001789 (0.115)
SIZE2	-.000270 (-1.177)	-.000311 (-1.512)	-.000132 (-0.579)	-.000068 (-0.326)
AVBA	.016132 (0.954)	.014314 (0.225)	.020715 (0.732)	.020802 (1.447)
AVMA	.016781 (0.600)	.006832 (0.253)	.020715 (0.732)	.025609 (0.929)
AVPHD	-.064975 (-0.287)	-.172030 (-1.010)	.088325 (0.214)	-.022249 (-0.194)
HC*AVPHD	.128100 (2.040)	.160490 (2.623)		
HC*SIZE	.000671 (0.313)	-.001821 (-0.953)		
HC*DEPHC	.049315 (1.630)	.055333 (3.182)		
INTER- CEPT	-.116530 (-0.453)	-.223830 (-1.056)	-.068685 (-0.264)	-.181090 (-0.861)
R-SQUARE	.3153	.2935	.2876	.2843
F-STAT	12.320	16.880	14.534	18.496
RSS	144.15	150.11	154.59	155.07
d.f.	321	325	324	326
SEE	.69961	.70627	.71033	.70980

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

It should be noted that the specifications estimated in Tables 7-1 and 7-2 are identical to those in Table 5-1 and were chosen specifically for the purposes of comparison rather than to find the best specification for Political Science and Sociology. Nonetheless, a comparison of Tables 7-1 and 7-2 with Table 5-1 is fairly revealing. The first point is that the same set of models fit the data much better for Economics and Sociology than for Political Science, although the objective of the exercise is not to fit the data, but rather to determine the appropriate specification and get the best possible estimate of the coefficients of that specification. Still, this result could be taken to suggest that the models which fit well for Economics and Sociology do not fit as well for Political Science. However, some care must be taken with this interpretation, since it is quite possible that the apparent weakness of the model with Political Science data is due to a problem with the use of a journals-only measure of research output, rather than with the production model itself. A second point to note with these results is the much weaker relationship between RES and SIZE in these regressions than was evident with data from Economics. In the case of Political Science, neither SIZE nor SIZE2 is significant in any regression, although HC*SIZE is significantly positive. In the case of Sociology, SIZE is significantly positive in regression #2 only at the 10 percent confidence level, although it is possible that the estimated values of the standard errors would fall if the data were corrected for the likely presence of non-spherical disturbances, and then both SIZE and SIZE2 would be significant in a feasible GLS regression. AVBA is not significant for either discipline, and for

Sociology it does not have the a priori expected sign. HC*AVPHD is significant in both sets of regressions, however negatively so in Political Science, and positively in Sociology. On the basis of this preliminary examination of the results of Table 7-1 and 7-2 it is clear that the results of Chapter 5 and Chapter 6, which were based on data drawn from Departments of Economics, cannot easily be generalized to other disciplines.(1)

Conclusion

Although the two disciplines used to test the stability of the production function over different departments were chosen to maximize the likelihood of finding a stable relationship, the results confirm the a priori presumption. The production relationship between inputs and outputs is fundamentally different in each academic discipline. Results derived from Departments of Economics cannot easily be generalized to other departments, even other social sciences. Thus any proposal which assumes or requires a commonality in production characteristics across departments is likely to be misleading.

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(1) It must be emphasized here that these results can only be regarded as preliminary indications since they are based on estimated equations which are likely misspecified. Stronger conclusions can only be made after a full specification search (such was undertaken for Economics in Chapter 5). However, this approach of comparing identically specified models across discipline is quite suggestive of similarities and dissimilarities between them.

7.3 Different Definitions of Research Output

The previous section looked at the question of how stable the estimated production function was across different disciplines. The production relationship estimated using data drawn from Departments of Economics could not easily be generalized to other disciplines. While this is an important result in terms of evaluating proposals for university organization, it does not affect the validity of the results presented in Chapter 5 since those results were based on the very presumption which has just been confirmed. As such the preceeding analysis is not so much sensitivity analysis as a test of generality. However, in this section a question which is crucial to the validity of the Chapter 5 results will be asked. How stable is the estimated production relationship for Departments of Economics over different definitions of research output? The reason this question is so crucial is that the definition of research output is highly problematic and if the results of the analysis are highly sensitive to the definition chosen, very little confidence can be placed in any study of university production.

In the empirical work presented in Chapter 5 the research output was measured as the unweighted sum of publications in journals surveyed the Social Science Citation Index. For the period chosen academic ists published in 196 different journals, some of which are major, 'ge, journals and others of which are very minor. In addition blications are long papers containing the results of much hers are one or two page notes which simply comment on previous publications. Because of this, it might well be argued that simply adding up number of articles published by any one individual in a given time period is a very crude measure of research output. Therefore, the Chapter 5 results might be very different if the measure of research output had been constructed to account for the prestige or length of the articles. In this section this possibility will be examined.

Of the 196 different journals in which Ontario's economists published articles between 1976 and 1981, only a few would be recognized as 'high quality' journals by members of the profession. In fact, it is more than likely that only a few would be recognized at all by the average academic economist.(1) While a substantial number of journal rankings have been devised and discussed in the literature (see Chapter 2) all such schemes are fundamentally subjective and arbitrary and no one scheme can ever devised that would meet all possible objections. Bearing this in mind, no attempt was made to devise the 'perfect' publication based measure of research output. Instead, the production function was re-estimated using several other measures of research output, and the results of these estimations were examined to determine whether or not the conclusions of Chapter 6 were affected by the specific measure of research output chosen.

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(1) It should be noted that the distribution of publications amongst journals is quite thin. For example, during the time period studied the journal in which the most publications appeared was the Canadian Journal of Economics, which garnered only 12 % of all articles published by Ontario's economists, and only six other journals had more than two percent of the publications.

For the purposes of this analysis, four other approaches to measuring research output were used to construct the dependent variable. The first approach was simply to weight each publication by its length. This approach was chosen to counter the argument that a (say) twenty page article constitutes twice the output of a ten page article. However, one implication of this approach is that three ten page articles will have the same value as one thirty page article. While this approach thus seems no more defensible than the one used in the construction of RES, it should be remembered that the objective is to determine how sensitive the results are to various approaches, not to find the best possible approach (on the prior assumption that there can be no one perfect measure). The variable constructed using this approach was labeled RES(PG).

The second approach was to weight by article length, and also by quality of journal. This approach yielded two different measures of research output. The first of these, which was labeled RES(24), was compiled by counting only publications in one of 24 'top' journals. This variable weights all publications in one of the 'top 24' journals by their page length, while assigning all other publications a weight of zero. It should be noted that the list of 'top 24' journals includes neither the <u>Canadian Journal of Economics</u>, nor <u>Canadian Public Policy</u>, which were the two journals most published in by Ontario Economists. Further, the list contains a number of questionable inclusions and exclusions. Thus, this variable, athough previously employed in the literature, leaves much to be desired.(1)

In order to create a variable which would weight for quality, but which is more defensible, a third variable was created based on a very comprehensive and sophisticated journal ranking scheme devised by Liebowitz and Palmer (1984). In the Liebowitz-Palmer (LP) paper, journal rankings were created based on the ratio of citations to articles published. One of the LP ranking schemes, reported in the second column of Table 2 of their paper, ranks journals by impact adjusted citations per character. The journals were given an index number ranging from 100 (for the <u>Journal of Political Economy</u>) to 0.01. One hundred journals were so ranked (the <u>CJE</u>'s index number is 17.99), and all unranked journals were given an index number of zero. This LP index number was multiplied by the number of pages to create the desired dependent variable for each faculty member. This variable was labeled RES(LP2).

Finally, the LP ranking system was used to create a dependent

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(1) The twenty-four journals, which were chosen to represent top quality journals and have been used in similar studies such as Niemi (1975), Smith and Gold (1976) and Graves et al. (1982) are: American Economic Review, Econometrica, Economic Development and Cultural Change, Economic Inquiry, Economic Journal, Economica, Industrial and Labor Relations Review, International Economic Review, Journal of Business, Journal of Economic History, Journal of Economic Theory, Journal of Finance, Journal of Human Resources, Journal of Law and Economics, Journal of Money, Credit, and Banking, Journal of Political Economy, Journal of Regional Science, Journal of the American Statistical Association, National Tax Journal, Oxford Economic Papers, Quarterly Journal of Economics, Review of Economic Studies, Review of Economics and Statistics, Southern Economic Journal.

variable in which articles were weighted by the quality of journal, but not by the number of pages. To create this variable, the fourth column in Table 2 (Liebowitz and Palmer, 1984, pg. 85-87) was employed. This LP ranking scheme created an index number for journals based on the impact adjusted citations per article. Thus, the variable RES(LP4) was created by summing the total number of articles, weighted by the index number of the journal published in, for each individual faculty member.

The full set of regressions for each of these dependent variables is reported in Tables A-7 to A-10 in the Appendix. However, Table 7-3 below provides insight into the results by comparing the OLS regressions of the maintained specification for different dependent variables. As Table 7-3 indicates, the results reported in Chapters 5 and 6 are not highly sensitive to the approach used to create the dependent variable.

In each of the regressions reported in Table 7-3 the data indicate increasing returns to scale at a decreasing rate. In each case the coefficients on SIZE and SIZE2 have the same signs, the same relative sizes, and are significant at the 1% level. In each case the coefficient on HC*DEPHC is significantly positive, which implies that a less equal distribution of human capital will increase production. Thus the two major results of Chapter 6 are not sensitive to the approach taken to the measurement of research output.

TABLE 7-3: OLS Estimation of the Production Function with Different Measures of Research Output

Variables	Dependent Variable				
	RES	RES(PG)	RES(24)	RES(LP2)	RES(LP4)
SIZE	.030886	.531580	.318120	18.6020	.682440
	(3.045)	(3.966)	(3.920)	(4.496)	(4.168)
SIZE2	-.000258	-.004132	-.002290	-.134210	-.004912
	(-2.682)	(-3.256)	(-2.981)	(-3.426)	(-3.169)
AVBA	-.014658	-.242400	-.112200	-8.99090	-.385470
	(-1.861)	(-2.329)	(-1.781)	(-2.978)	(-3.032)
AVMA	-.112780	-.702410	-.517900	-45.8960	-1.38160
	(-0.975)	(-1.529)	(-0.559)	(-0.972)	(-0.740)
AVPHD	.050013	-1.09000	-1.72010	-113.380	-3.74180
	(0.257)	(-2.573)	(-1.104)	(-1.427)	(-1.191)
HC*AVPHD	-.161620	-.855140	-.231430	-11.6140	-.718330
	(-3.764)	(-1.507)	(-0.674)	(-0.663)	(-1.036)
HC*SIZE	.001728	.020523	-.001865	-.019073	-.007368
	(1.907)	(1.714)	(-0.257)	(-0.052)	(-0.504)
HC*DEPHC	.094488	.576190	.317760	16.5600	.919200
	(6.536)	(3.016)	(2.747)	(2.808)	(3.939)
INTER-	.025311	-2.66690	-2.38270	-109.760	-3.07880
CEPT	(0.119)	(-0.946)	(-1.396)	(-1.261)	(-0.894)
R-SQUARE	.2971	.2343	.1069	.1436	.1550
F-STAT	21.078	15.263	5.969	8.361	9.149
RSS	418.59	73098	26796	69674000	109080
d.f.	399	399	399	399	399
SEE	1.0243	13.535	8.1951	417.88	16.534

Figures in brackets are t-statistics.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

Conclusion

It is clear that no one approach to using academic publications to measure research output will satisfy all possible objections. But all objections will revolve around the difficulty involved in comparing different publications. While admitting that (for example) a 25 page article in The American Economic Review is not the same as a two page article in Economics Letters (both highly respectable journals) the issue of how they are different can never be resolved. What this section has demonstrated is that the general results and conclusions of Chapters 5 and 6 are not sensitive to the choice of approach to measure the publication-based research output variable.

7.4 Different Definitions of Teaching Output

The previous section dealt with different approaches to defining and measuring research output. This analysis was important because the appropriate measure is so problematic. However this is not the case for the measurement of teaching output. As described in Chapter 2 a student-based measure (such as enrolment) is quite appropriate for a study of this nature. Instead three specific issues must be addressed. First, is enrolment the proper student-based measure to use? Second, did the arbitrary weighting of full and part time students distort the estimated results? And third, did the procedure for estimating the University of Toronto's undergraduate enrolment distort the estimated results?

With respect to the first issue, the answer is that of all possible student-based measures, enrolment is probably not the best. The two alternative measures which have been suggested or used in the literature are degrees granted and students taught. The former is probably less useful than enrolment in a one-year cross section study because degrees granted depend on previous years' enrolments. The latter is probably better since it is students in classes rather than students in programs that are actually taught by faculty. Thus if in a given university very few students were enrolled in degree programs in Economics but many took Economics courses, the use of program enrolment would be misleading. However it should be noted that this only creates a problem to the extent that the relationship between students enrolled in degree programs and student taught differs between institutions. One way to correct for this possible distortion is to include, in addition to enrolment in programs leading to degrees in Economics, enrolment in other programs. The logical choices are undergraduate enrolment in Commerce, for which Departments of Economics traditionally teach service courses, and undergraduate enrolment in the university as a whole.

In order to determine whether or not the use of Economics enrolment data rather than students taught data caused distortion to the results presented in Chapter 5 the basic model has been re-estimated with two additional variables. AVCOM is the ratio of Commerce enrolment to Economics faculty and AVTOT is the ratio of total undergraduate enrolment to Economics faculty. Unless no students except those who are enrolled in Economics take courses in Economics (which is clearly false) we would expect that an increase in enrolment in other departments would use teaching resources in Economics and thus lower research output cet. par. However if the ratio of Economics enrolment to students taught is the same in all institutions the Economics enrolment variable will function as a perfect proxy. To the extent that Economics enrolment is not a perfect proxy we would expect that the coefficients on AVCOM and AVTOT would be significantly negative. The results are presented in Table 7-4 below.

From the results presented in Table 7-4 it would appear that that distortion caused by using enrolment rather than students taught data is very minimal. None of the variables previously included are significantly affected by the inclusion of one or both of the new variables. The variables which are most affected are the enrolment figures, which is to be expected. If the basic model had been estimated with data on students taught rather than data on students enrolled the actual values of the coefficients would naturally be different and would have a slightly different interpretation. However the results of this analysis suggest that no difference in the general results or conclusions of the study would be expected from the use of data on students taught.

The second issue concerning the enrolment data was whether or not the aggregation of full and part time students using an arbitrary (although not unrealistic) weight of 1 full time student equals 5 part time students has distorted the results. In order to test this the basic model was re-estimated using several different weights. The estimated coefficients and the standard errors for these regressions are

TABLE 7-4: OLS Estimation of the Production Function with Data from Departments of Economics with Total University and Commerce Enrolment Variables

Variables	Regressions			
	1	2	3	4
HC	.014869		.171460	.159110
	(0.156)		(4.562)	(9.620)
HC2	-.001166		-.000997	
	(-0.400)		(-0.366)	
DEPHC	.164110		.164090	.182740
	(0.419)		(0.422)	(1.507)
DEPHC2	-.031446		.004991	
	(-0.271)		(0.044)	
SIZE	.033180	.036707	.038973	.038813
	(2.327)	(2.943)	(2.755)	(2.933)
SIZE2	-.000284	-.000321	-.000309	-.000308
	(-2.000)	(-2.553)	(-2.170)	(-2.261)
AVBA	-.011953	-.013643	-.013943	-.013981
	(-1.185)	(-1.550)	(-1.379)	(-1.407)
AVMA	-.142200	-.188920	-.171940	-.169850
	(-1.185)	(-1.325)	(-0.975)	(-1.150)
AVPHD	.040643	.112860	-.276070	-.273800
	(0.152)	(0.510)	(-1.140)	(-1.143)
HC*AVPHD	-.147690	-.186780		
	(-2.700)	(-3.618)		
HC*SIZE	.001511	.001620		
	(1.375)	(1.772)		
HC*DEPHC	.092410	.094570		
	(2.243)	(6.454)		
AVCOM	.000836	.001014	.000470	.000405
	(0.217)	(0.333)	(0.121)	(0.127)
AVTOT	.000429	.000629	.000412	.000394
	(0.481)	(0.959)	(0.457)	(0.597)
INTER-	-.368270	-.301180	-.427920	-.421150
CEPT	(-0.664)	(-0.597)	(-0.766)	(-0.777)
R-SQUARE	.2998	.2988	.2833	.2831
F-STAT	12.018	16.920	14.231	17.460
RSS	416.97	417.54	426.78	426.93
d.f.	393	397	396	398
SEE	1.0300	1.0255	1.0777	1.0727

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

reported in Table A-11 in the Appendix. The results show very little difference between the lowest weight used for part time students (0) and the greatest weight used (.6). As the weight was increased from 0 to .6 the coefficients on some variables were unchanged (HC), some fell, (DEPHC, AVMA, AVPHD) and some rose, (SIZE, SIZE2, AVBA) but in no case was the largest value of the coefficient outside the 1% confidence interval of the coeficient at its smallest, and vice versa. In other words the aggregation of full and part time students within a reasonable range had no significant effect on the results.

The final issue to be dealt with is whether the creation of AVBA for the Univesity of Toronto distorted the results. In the original estimation it was assumed that the ratio of undergraduate students to faculty members at the University of Toronto in the Departments of Economics was equal to the provincial average. Since the University of Toronto has the largest (most faculty) department of Economics in the Province and since the ratio of students to faculty is an important right-hand side variable, it was feared that the results presented in Chapter 5 were determined, at least in part, by assumption. In order to check the degree to which the specific assumption about the enrolment at the University of Toronto determined the results the basic model was re-estimated with different values for AVBA at the University of Toronto.

The basic model of Chapter 5 was reestimated with AVBA at the University of Toronto set first at .5 times the provincial average and then at 1.5 times the provincial average. The results of this procedure (reported in Table A-12 in the Appendix) were that none of the estimated coefficients in either case were outside the 1% confidence interval of the originally estimated coefficients. In fact, none of the newly estimated coefficients were more than one third of a standard error away from the originally estimated coefficients; most varied far less. While it is true that the originally estimated standard errors will be biased in the event of measurement error (which is effectively what this is), these results suggest that the procedure used to calculate the value of AVBA at the University of Toronto did not significantly distort the results reported in Chapter 5. If the 'correct' value could have been obtained the results of the estimation would not be significantly different from those reported in Chapter 5.

Conclusion

Three different issues relating to the definition and measurement of the teaching output have been examined. The strong conclusion of this analysis is that the results of Chapter 5 are very robust with respect to the objective definition of teaching output and the data collection and aggregation procedures used. It appears that the same conclusions and essentially the same numerical values of parameters would result from other reasonable definitions and procedures.

7.5 Summary

In this chapter two different issues were addressed. The first was whether or not the results obtained from estimating the basic production model with data from Departments of Economics could be generalized to other departments. The result, not suprisingly, was negative. The second issue was whether or not the strong results reported in Chapter 5 had been determined in any way by the choice of definition, aggregation, or measurement technique employed in the creation of the output variables. Again the answer is negative. The clear indication of the analysis performed in this chapter is that the characteristics of the production relationship are revealed despite the need to use problematic and sometimes arbitrary procedures in creating these data, not because of it.

CHAPTER 8

CONCLUSIONS

8.1 Introduction

In Chapter 1 various proposals for the future organization of the university system in Ontario were discussed, and three specific proposals were identified both as plausible solutions to the current funding difficulties, and as depending for their effectiveness on some implicit assumptions about the nature of academic production. However, there has never been any rigorous empirical examination of the actual production process at Ontario universities, and in fact, most of the existing cost studies which have been done for various jurisdictions in North America or the U.K. have assumed away those aspects of the production process which are perhaps most crucial.

In Chapters 3 and 4 of this study a model of university production was specified. In modelling the production process, the quality of education was assumed constant. In Chapter 5 the model was estimated using data drawn from departments of economics. Finally, in Chapter 6 the results of the estimated production function were employed to evaluate the potential cost savings or efficiency gains, measured in changes in research output, which are indicated by each of the three proposals. the three proposals.

It should be noted at the outset that the three proposals chosen for examination do not represent the only, or even the best, proposals.

For example, one proposal which would certainly find adherents, and which is not discussed here, would be for the provincial government to allow universities to set their own tuition levels. Instead, these particular proposals were chosen to provide insight on a whole class of proposals: those which are based on an implicit model of academic production. It should also be noted that the results of the analysis are subject to certain caveats. Some of these caveats should be applied to any production study, some are specific to a study of academic production and some are specific to the interpretation of individual proposals.

In this chapter, the three proposals are re-examined. In each case the results of the empirical analysis, and the attendant caveats, are summarized. Finally, the implications of the study as a whole for the policy issues involved in the current debate are discussed.

8.2 Proposal #1: System Rationalization

The first proposal which was examined has been described in this thesis as the system rationalization proposal. This usage is quite broad, intending to include any proposal which suggests that efficiency gains could be realized through a re-organization of the university system, such that the roles of different institutions, or at least different departments within the same discipline, are more narrowly defined. Practically, this implies a two-tier system, in which some departments would be designated (at least implicitly) as Tier One departments and would specialize in graduate teaching and research, and other departments would be designated as Tier Two departments and would specialize in undergraduate teaching. In the analysis of Chapter 6 a two tier system was regarded as a proposal to improve efficiency by exploiting the supposed positive relationship between graduate teaching and research and the supposed increasing returns to departmental human capital on the production of research. This proposal has intuitive appeal and, in addition, it has the important advantage that it can be applied on a department-by-department basis rather than on a university-by-university basis. That is, one university could have a Tier One department of Economnics but a Tier Two department of Political Science.

The estimated production function for the research output of faculty members employed in departments of economics was investigated to determine whether or not a proposal of this type was likely to generate efficiency gains (measured in terms of research output) if it is applied to departments of economics. The results of that analysis indicates that, <u>cet. par.</u>, as the average level of human capital increases in a department, the average level of research output rises at an increasing rate. This implies that, for any given level of human capital, province-wide research output would be increased if the distribution of human capital became less equal across departments, within the discipline of economics. This result clearly supports the system rationalization proposal. However, the gains in efficiency which could be realized from hypothetical reorganizations of the existing level of human capital in departments of economics were disappointing. For distributions within the range of observations a gain in research output of less than 10 percent was predicted. Very much larger gains would be predicted outside the range of observations, but these must remain highly speculative.

On the other hand, there was no evidence at all to suggest that a reorganization of teaching loads, either by having all graduate students taught at Tier One departments, or by shifting undergraduates towards Tier Two departments, would increase overall research production. In the case of graduate teaching, there is no evidence to suggest that research is more efficiently produced in departments that have doctoral programs. On the contrary, all evidence suggests that the effect of graduate teaching in the production function for research is, on balance, negative. Further, the estimated form of the production function suggests that if students were moved from one department to another, without changing the number of faculty at either department, no change in the province-wide output of research would occur. However, if all graduate students were congregated at a few large departments, and faculty resources were transferred with them, total provincial research output would rise, because of the higher efficiency of large departments.

While we do expect some gains in efficiency from a 'rationalized' system, there are two important caveats to be considered. First, this study has assumed that the quality of the teaching output is constant across departments, within one discipline. However, it may not be possible to make this assumption in a two-tier university system. It may well be that the quality of education provided at departments designated as Tier Two departments would diminish over time. In this case the system rationalization proposal must really be viewed as a way of reducing the amount of teaching output actually produced in the province. This may not be a bad thing, and if this is the objective, system rationalization may be the best way to achieve it. However, this thesis has proceeded on the assumption that these types of proposals are aimed at either increasing effiency, or reducing the levels of inputs, not at changing the nature of education received at Ontario Universities.

Second, this study has been concerned only with the relative amount of production which would be generated in alternative hypothetical systems. It has not considered the costs of system transformation. The results of the analysis suggest that the costs of system transformation do not have to be very high before the gains in efficiency are negated.

The conclusion that can drawn from the above analysis is that, looked at as a scheme to improve efficiency, the two-tier approach has little merit in departments of economics. However, there are two other ways to look at this approach. The first is that the real objective of this type of approach is to improve the quality of graduate teaching by having all graduate students taught at departments which are strongly research oriented. This would imply that graduate students at low research output departments are not getting the same quality of education as those at high research output departments. This proposition may or may not be true; it is not testable using the techniques of this study. However, even if true, it does not alter the basic conclusion presented above, that if graduate students are congregated at Tier One departments no significant efficiency gains can be expected (in terms of increased research output), outside those which would occur if faculty resources end up being more concentrated in larger departments as a result. If, in fact, high research output environments are best for graduate training, even greater gains may be associated with the two-tier system.

A second way to view two-tier type proposals is not as an approach to increasing efficiency but rather as a way to lower inputs. Looked at this way the proposal does not suggest that the creation of two tiers of departments will lead to more research output, but that with a higher teaching load and little or no research responsibilities at Tier Two departments fewer faculty members and less human capital will be required. However, even viewed as a special case of the input reduction scheme the efficiency questions of Chapter 6 are important. Unless a two-tier system is more efficient, it is not a better way to reduce inputs than an equal percentage reduction at each department. Based on the efficiency analysis it appears that in departments of Economics there are definite, if limited, advantages to cutting inputs at certain designated Tier Two departments, rather than to cut inputs across the board, assuming that these cuts will result in less research output, but not lower the quality of the teaching output provided.

A number of specific proposals have been made about the future organization of the university system in Ontario that fall within the general outline of the two tier approach described here. Proposals of this type may result in a change (for better or worse) in the quality of education and this may be regarded either as an important caveat or as the objective of the exercise. However if the proposals are meant to be taken as solutions to the current funding difficulties of the universities, the efficiency implications are crucial. The evidence from departments of Economics suggests that the system of university organization which would result from the application of these proposals would be more productive than the status quo. However, the gains are sufficiently limited that if the costs of transforming the system are significant, it is unlikely that the benefits of the transformation would outweigh the costs.

8.3 Proposal #2: Department Closures

The second proposal which was discussed was that of closing one or more small departments and allowing the remaining departments to grow in size. Unlike the first proposal, which could be applied on a department- by-department basis, and which could be applied to a greater or lesser degree, this proposal is very limited in the ways it can be applied. Obviously, whole universities can be closed, as has happened in other jurisdictions. Further, specific professional programs such as engineering, architecture, medicine, or law can be excised from a given university. However, it is difficult to imagine how it would be possible to close departments in the traditional academic disciplines such as mathematics, history, or political science while leaving the university still in existence. Thus in Chapter 6 when the hypothetical experiments of closing various departments of economics were performed, it must be understood that such a proposal would make sense only if the entire university closed as well.

This is an important and unfortunate caveat. The results of Chapter 6 demonstrate very clearly that in departments of economics, output increases (at a decreasing rate) as the number of faculty members increase, cet. par. In fact, the calculation of optimal department size, which indicated that province-wide research output would be maximized in departments of economics (given the status quo level of enrolments) when the number of faculty members is approximately equal to 60, was very stable over differing specifications and even differing objective definitions of research output. Further, the experiments demonstrated that fairly significant efficiency gains could be achieved by closing those departments which are well below optimum.

Unfortunately, as the results of Chapter 7 demonstrate, there is no guarantee that all departments are subject to increasing returns to scale. Thus, closing several small universities would create efficiency gains in economics but these gains may not be matched by similar gains in other departments. This makes the proposal to close departments and increase research output far more problematic than it might have appeared after an examination of the Chapter 6 results.

In fact, this result, that strong economies of scale exist in departments of economics, would probably be of more value in an expanding system, rather than one that is contracting. If the system was expanding, it would be clear that the expansion should take the form of bring existing departments up to optimal size, rather than creating new departments. However, in a contracting system, it is difficult to see how these scale economies can be effectively exploited short of closing whole universities.

Finally, it might be argued that the proposal to close universities does not depend on the existence of economies of scale within each discipline, but rather on the argument that average fixed costs could be reduced in this way, and that any gain in efficiency would constitute an extra savings. According to Statistics Canada (publication # 81-202) total university expenditure in Ontario in 1981-82 was $1.764 billion. Of that, the major use of funds is operating expenditures on instruction and sponsored research ($1.029 billion, or 58.3%). This expenditure could be reduced by increasing efficiency or by producing less instruction and research, but it is not part of the fixed costs which may be reduced by university closures. In other words, if one or more universities were closed, but the same levels of teaching and research were to be maintained province wide, there is no reason for this figure to be reduced unless fewer, larger universities are more efficient, as they clearly are in departments of economics. Expenditure on libraries, computing, administration, and physical plant amounted to $400.7 million, or 22.7% of the total. It is this figure which might be reduced by eliminating unnecessary duplication. It should be noted, however, that these expenditures are not really fixed costs, but rather central costs (with the possible exception of administration which could be considered as fixed at each university and invariant to the size or scope of the university's operations). Thus to say that reducing the number of universities would save on library, computing, and physical plant expenditures really implies economies of scale in these services. However, there is no reason a priori to suspect economies of scale in these services. And in fact, the per student levels of expenditures on these types of items do not seem to fall for large universities (see Table A-13 in the Appendix).

Nor is there any reason to believe that the existing physical plant is underutilized. Judging by the evidence of the OCUA's annual reports, the universities are operating at capacity now. This means that, if output were to be maintained, the physical capacity of the closed universities would have to be added to the remaining universities.

In all, it appears that if any cost savings are to be realized by creating fewer, larger universities those cost savings will have to come from exploiting economies of scale. There are strong grounds for believing that such economies should exist and, at least for departments of economics, the hypothesis of economies of scale are supported by the data. However the size of potential efficiency gains from university closures must be regarded with caution since it is clear that the existence and nature of these gains vary from department to department.

Finally, just as the two-tier proposal can be regarded not as an approach to saving through efficiency but rather as an approach to saving through input (and thus output) reduction so too can the proposal of university closures be regarded in this light. Although, given the provincial government's long-standing commitment to 'accessability', a proposal simply to reduce capacity and output by closing one or more universities, and not to increase the enrolment at the remaining institutions, seems unlikely to be implemented.

8.4 Proposal #3: Input Reductions

The last two sections have looked at proposals which, for the purposes of this study, have been interpreted as ways in which to reduce costs by improving efficiency. In this section, the third proposal will be discussed. This proposal is for a reduction in the size and scope of the university system in Ontario by simply reducing the levels of inputs and accepting the resultant loss in production. As an approach to reducing costs this proposal will work. The only issue is the determination of the most efficient way to implement such reductions.

The analysis of Chapter 6 investigated the relationship between input reductions and expected reduction in one output (research) holding the other output (teaching) constant, in departments of economics. The results of that analysis do shed some light on this issue. First, it should be noted that across the board cuts in expenditure on faculty of 10% would cause a 12.42% fall in research output. However, approximately the same reduction in faculty costs would occur if the departments at Brock, Trent, Wilfrid Laurier, and Laurentian were closed, yet the loss of research would be only half as great.(1) Thus, it would appear that the process of underfunding existing institutions, which is an approach to across the board input reductions, does reduce output more than closing some existing departments, but the actual reduction in output loss is surprisingly small. This loss in research output would be further reduced if the cuts were not applied across the board, but rather were implemented in such a way as to move in the direction of a two-tier system.

8.5 Summary

In this chapter the three proposals were reexamined. The general conclusion that emerges from the analysis is that, if the intention of the government is to reduce university expenditures while maintaining the goal of accessibility and the quality of education, a reduction in research output must be expected. In departments of economics, which show strong economies of scale, it appears that the advantage of department closures, over across the board cuts, is large in relative terms, but surprisingly small in absolute terms. It also appears that some move towards a two-tier system would reduce the loss in research output, although only very slightly. Thus, evidence from departments of economics does not provide strong support for either

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(1) In fact, the loss in manpower would be 10.54% if those four departments were closed, but average human capital is lower than the provincial average in those departments. The predicted loss in output is 2.40%. See Table 6-2 on page 146.

system rationalization or department closures as an alternative to underfunding.

APPENDIX

TABLE A-1: Descriptive Statistics on Variables Used in Regression Analysis

Variables	Mean	Standard Deviation	Minimum	Maximum
Individual				
RES	.74510	1.2096	0.0000	7.0000
HC	2.0588	3.2446	0.0000	21.000
DEPHC	2.0472	.93529	.30000	3.3514
SIZE	43.463	27.299	7.0000	88.000
AVBA	14.397	7.7215	2.8889	32.337
AVMA	.80364	.49373	0.0000	.80364
AVPHD	.78273	.72075	0.0000	1.8977
Departmental				
AVRES	.54398	.43016	0.0000	1.3966
DEPHC	1.6061	.96587	.30000	3.3514
SIZE	27.200	21.900	7.0000	88.000
AVBA	13.726	8.8440	2.8889	32.337
AVMA	.74567	.61880	0.0000	1.6000
AVPHD	.41132	.60246	0.0000	1.8977

Note: Individual means represent the average values over all 408 individuals, departmental means represent the average values over 15 departments. They will not, in general be the same. The mean value of HC and DEPHC for individuals differ because of rounding error.

TABLE A-2: OLS Estimation of the Production Function for University Research: General Form

Variables	Regressions 1	2	3	4	5
HC	-.077005 (-0.419)	-.052542 (-0.306)			
HC2	-.001150 (-0.393)				
DEPHC	.307280 (0.708)	.058116 (0.470)			
DEPHC2	- 088551 (-0.743)				
SIZE	.033938 (1.239)	.031173 (2.615)	.033811 (3.136)		.031702 (1.492)
SIZE2	-.000270 (-0.907)	-.000250 (-2.182)	-.000275 (-2.760)		-.000247 (-1.074)
AVBA	.012954 (0.230)	-.016840 (-1.682)	- 018059 (-0.769)	.031170 (0.698)	.041158 (0.936)
AVBA2	-.000749 (-0.467)			-.000903 (-0.776)	-.001471 (-1.252)
AVMA	-.703360 (-1.230)	-.095508 (-0.683)	- 100560 (-0.769)	-.370510 (-0.714)	-.555150 (-1.050)
AVMA2	.414840 (1.147)			.202320 (0.623)	.335110 (0.983)
AVPHD	.239090 (0.358)	-.047273 (-0.186)	010874 (0.053)	.980200 (2.867)	.182220 (0.288)
AVPHD2	-.098002 (-1.754)			-.405860 (-2.476)	-.104520 (-0.289)
HC*AVBA	003911 (0.806)	.003609 (0 459)	002662 (0.829)	.000367 (0.119)	
HC*AVPHD	-.153170 (-0.806)	-.150870 (-1.795)	-.135250 (-2 214)	-.183770 (-3.3260)	-.154750 (-3.548)
HC*SIZE	.001406 (0 793)	001450 (0.842)	.001064 (0.767)	002279 (1.911)	001653 (1.805)
HC*DEPHC	.109220 (2.268)	.094143 (2.141)	.086293 (3.760)	.091092 (4.043)	.092531 (6.301)
INTER-CEPT	-.394410 (-0.846)	-.338130 (-0.122)	.006129 (0.028)	.020280 (0.056)	-.373560 (-0.898)
R-SQUARE	.3030	.2991	2983	.2921	.3004
F-STAT	9.974	14 050	16.876	14.857	15.455
RSS	415.05	417.35	417.86	421.53	416.63
d.f.	390	395	397	396	396
SEE	1.0316	1 0279	1.0259	1.0317	1.0257

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

<u>TABLE A-3</u>: OLS Estimation of the Production Function for University Research: General Form, Cont'd

Variables	Regressions				
	1	6	7	8	9
HC	-.077005				.038200
	(-0.419)				(0.309)
HC2	-.001150				
	(-0.393)				
DEPHC	.307280				
	(0.708)				
DEPHC2	-.088551				
	(-0.743)				
SIZE	.033938				
	(1.239)				
SIZE2	-.000270				
	(-0.907)				
AVBA	.012954	-.011564	.024084		-.011015
	(0.230)	(-1.685)	(0.539)		(-1.553)
AVBA2	-.000749		-.000766	-.000359	
	(-0.467)		(-0.656)	(-1.935)	
AVMA	-.703360	-.055598	-.257300		-.051508
	(-1.230)	(-0.459)	(-0.489)		(-0.423)
AVMA2	.414840		.136940	-.026853	
	(1.147)		(0.415)	(-0.366)	
AVPHD	.239090	.229790	.941050		.231820
	(0.358)	(2.625)	(2.600)		(2.637)
AVPHD2	-.098002		-.388690	.078384	
	(-1.754)		(-2.169)	(1.760)	
HC*AVBA	.003911	.002535	.003411	001860	001646
	(0.806)	(1.209)	(1.559)	(0.905)	(0.463)
HC*AVMA	.013460	- 053461	-.041491	-.058108	-.060665
	(0 187)	(-1.322)	(-1 012)	(-1.428)	(-1 298)
HC*AVPHD	-.153170	-.123130	-.113650	-.111310	-.114730
	(-0.806)	(-3.900)	(-3.547)	(-3.502)	(-2.754)
HC*SIZE	.001406				
	(0 793)				
HC*DEPHC	.109220	.116540	.103400	.117670	106040
	(2.268)	(6.188)	(5.239)	(6.162)	(2.728)
INTER-CEPT	- 394410	.474300	.076383	.474670	.457250
	(-0.846)	(3.012)	(0.211)	(4.252)	(2.737)
R-SQUARE	3030	.2775	.2866	.2727	.2777
F-STAT	9.974	21.946	15.947	21.429	19.171
RSS	415.05	430.25	424.84	433.08	430.15
d.f.	390	400	397	400	399
SEE	1.0316	1.0371	1.0345	1.0405	1.0383

Dependent variable: RES. Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE A-4: Davidson-McKinnon J-test of Regression #2 vs. Regression #4

Variables	H0: Specification #2 is True H1: Specification #4 is True	H0: Specification #4 is True H1: Specification #2 is True
HC		.015368 (0.302)
DEPHC		.082540 (0.710)
SIZE	.019154 (0.963)	.082540 (0.035)
SIZE2	-.000159 (-0.926)	.000006 (0.044)
AVBA	-.009272 (-0.833)	.000551 (0.038)
AVMA	-.064161 (-0.473)	.008908 (0.070)
AVPHD	.074604 (0.377)	-.106310 (-0.471)
HC*AVPHD	-.140910 (-2.684)	
HC*SIZE	.001400 (1.366)	
HC*DEPHC	.073720 (2.197)	
RES-HAT1	.309880 (0.686)	
RES-HAT2		.898070 (2.982)
INTER-CEPT	.006495 (0.030)	-.094116 (-0.376)
R-SQUARE	.2979	.2980
F-STAT	18.764	21.170
RSS	418.09	418.05
d.f.	398	399
SEE	1.0249	1.0236

Dependent variable: RES. Figures in brackets are t-stats. Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60. RES-HAT1 is the predicted value of the dependent variable from specification #4, RES-HAT2 is the predicted value of the dependent variable from specification #2.

TABLE A-5: RESET Test Results for the Maintained Production Function Specification

Variables	Regressions			
	1	2	3	4
SIZE	.031557	.030698	.030841	.026919
	(2.953)	(3.015)	(3.038)	(0.993)
SIZE2	-.000262	-.000257	-.000259	-.000227
	(-2.649)	(-2.670)	(-2.696)	(-1.015)
AVBA	-.014985	-.014554	-.014585	-.012366
	(-1.862)	(-1.844)	(-1.851)	(-0.859)
AVMA	-.114430	-.113060	-.114500	-.081877
	(-0.985)	(-0.976)	(-0.988)	(-0.532)
AVPHD	.046253	.053281	.055799	.013759
	(0.236)	(0.273)	(0.296)	(0.070)
HC*AVPHD	-.170440	-.154760	-.148380	-.164680
	(-2.781)	(-3.050)	(-3.113)	(-1.082)
HC*SIZE	.001809	.001674	.001643	.002000
	(1.822)	(1.797)	(1.793)	(1.143)
HC*DEPHC	.099641	.090576	.001688	.089509
	(3.396)	(4.290)	(4.642)	(0.951)
INST2	-.015027			.543550
	(-0.201)			(0.524)
INST3		.003224	.001688	-.375640
		(0.255)	(0.642)	(-0.947)
INST4			.001688	.060840
			(0.642)	(1.257)
INTER-CEPT	.016623	.032205	.037599	-.020833
	(0.076)	(0.150)	(0.175)	(-0.086)
R-SQUARE	.2971	.2972	.2978	.3073
F-STAT	18.696	18.699	18.754	15.972
RSS	418.54	418.52	418.15	412.48
d.f.	398	398	398	396
SEE	1.0255	1.0255	1.0250	1.0206

Dependent variable: RES. Figures in brackets are t-stats. Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60. INST2, INST3, and INST4 are the predicted dependent variable from the maintained specification taken to the second, third, and fourth powers, respectively.

TABLE A-6: Distribution of Human Capital among Ontario's Academic Economists

Percent of Faculty	Percent of HC	Percent of HC(LP4)
Top percentile	10.2	14.3
First decile	49.5	69.4
Secon decile	22.4	19.6
Third decile	14.8	8.1
Fourth decile	6.4	2.7
Fifth decile	4.9	0.1
Sixth decile	1.7	0.0
Bottom 4 deciles	0.0	0.0

Note: HC is calculated as the unweighted sum of publications. HC(LP4) is calculated as the sum of publications weighted by the journal weight given in Liebowitz and Palmer (1984), Table 2, column four. Total number of faculty equals 408.

TABLE A-7: OLS Estimation of the Production Function with Data from Departments of Economics with RES(PG) as Dependent Variable

Variables	Regressions			
	1	2	3	4
HC	-.020858 (-0.016)		2.08920 (4.249)	1.64220 (7.578)
HC2	-.051568 (-1.344)		-.036057 (-1.013)	
DEPHC	-.644760 (-0.165)		-1.67290 (-0.438)	.422540 (0.292)
DEPHC2	.098084 (0.086)		.613840 (0.571)	
SIZE	.528200 (3.504)	.531580 (3.966)	.570940 (3.872)	.579210 (3.958)
SIZE2	-.004062 (-2.750)	-.004132 (-3.256)	-.004004 (-2.724)	-.004183 (-2.933)
AVBA	-.245690 (-2.191)	-.242400 (-2.329)	-.262800 (-2.355)	-.257420 (-2.317)
AVMA	-.706450 (-0.439)	-.702410 (-0.459)	-.974610 (-0.609)	-.911030 (-0.573)
AVPHD	-1.32100 (-0.383)	-1.09000 (-0.424)	-3.22030 (-1.046)	-2.53620 (-0.900)
HC*AVPHD	-.896200 (-1.245)	-.855140 (-1.507)		
HC*SIZE	.021194 (1.465)	.020523 (1.714)		
HC*DEPHC	.828400 (1.527)	.576190 (3.071)		
INTER- CEPT	-2.09710 (-0.486)	-2.66690 (-0.946)	-2.72350 (-0.635)	-4.06790 (-1.255)
R-SQUARE	.2379	.2343	.2308	.2284
F-STAT	10.276	15.263	13.269	16.911
RSS	72755	73098	73432	73665
d.f.	395	399	398	400
SEE	13.752	13.535	13.583	13.571

Dependent variable: RES(PG). Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE A-8: OLS Estimation of the Production Function with Data from Departments of Economics with RES(24) as Dependent Variable

Variables	Regressions			
	1	2	3	4
HC	-.879580		.579640	.454600
	(-1.160)		(1.945)	(3.462)
HC2	-.025143		-.010084	
	(-1.084)		(-0.467)	
DEPHC	-.877240		-1.79290	.213890
	(-0.370)		(-0.775)	(0.243)
DEPHC2	.072650		.605670	
	(0.105)		(0.929)	
SIZE	.307810	.318120	.330550	.339760
	(3.378)	(3.920)	(3.699)	(3.832)
SIZE2	-.002273	-.002290	-.002416	-.002608
	(-2.542)	(-2.981)	(-2.712)	(-3.018)
AVBA	-.117100	-.112200	-.121190	-.115880
	(-1.727)	(-1.781)	(-1.791)	(-1.721)
AVMA	-.548400	-.517900	-.674450	-.585840
	(-0.564)	(-0.559)	(-0.695)	(-0.609)
AVPHD	-1.18590	-1.72010	-2.38350	-1.69560
	(-0.570)	(-1.104)	(-1.278)	(-0.993)
HC*AVPHD	-.576940	-.231430		
	(-1.326)	(-0.674)		
HC*SIZE	.004349	-.001865		
	(0.497)	(-0.257)		
HC*DEPHC	.781780	.317760		
	(2.384)	(2.747)		
INTER-	-.970570	-2.38270	-1.32660	-2.83950
CEPT	(-0.372)	(-1.396)	(-0.510)	(-1.446)
R-SQUARE	.1139	.1069	.1007	.0984
F-STAT	4.233	5.969	4.951	6.236
RSS	26585	26796	26982	27051
d.f.	395	399	398	400
SEE	8.2039	8.1951	8.2338	8.2236

Dependent variable: RES(24). Figures in brackets are t-stats. Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE A-9: OLS Estimation of the Production Function with Data from Departments of Economics with RES(LP2) as Dependent Variable

Variables	Regressions			
	1	2	3	4
HC	-34.6570 (-0.900)		50.7110 (3.348)	28.7010 (4.288)
HC2	-2.75540 (-2.342)		-1.77560 (-1.616)	
DEPHC	-42.3760 (-0.353)		-102.760 (-0.874)	4.06270 (0.091)
DEPHC2	-.200800 (-0.006)		31.3410 (0.946)	
SIZE	18.4920 (4.000)	18.6030 (4.496)	19.5520 (4.304)	19.9770 (4.421)
SIZE2	-.136440 (-3.007)	-.134220 (-3.426)	-.142420 (-3.145)	-.151630 (-3.443)
AVBA	-9.43230 (-2.741)	-8.98920 (-2.798)	-9.64160 (-2.802)	-9.36450 (-2.727)
AVMA	-48.4010 (-0.981)	-45.9260 (-0.973)	-54.4750 (-1.106)	-51.2160 (-1.044)
AVPHD	-86.2170 (-0.816)	-113.340 (-1.427)	-140.580 (-1.483)	-105.530 (-1.213)
HC*AVPHD	-26.4750 (-1.199)	-11.6110 (-0.663)		
HC*SIZE	.231560 (0.522)	-.019012 (-0.051)		
HC*DEPHC	43.5840 (2.619)	16.5570 (2.807)		
INTER-CEPT	-44.5370 (-0.337)	-109.780 (-1.261)	-60.8010 (-0.460)	-129.960 (-1.298)
R-SQUARE	.1586	.1436	.1432	.1361
F-STAT	6.205	8.361	7.391	9.005
RSS	68451000	69674000	69704000	70278000
d.f.	395	399	398	400
SEE	416.28	417.88	418.49	419.16

Dependent variable: RES(LP2). Figures in brackets are t-stats.
Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE A-10: OLS Estimation of the Production Function with Data from Departments of Economics with RES(LP4) as Dependent Variable

Variables	Regressions 1	2	3	4
HC	-2.14010		1.89550	1.17700
	(-1.406)		(3.142)	(4.422)
HC2	-.102070		-.057962	
	(-2.194)		(-1.327)	
DEPHC	-.327630		-2.97970	.602150
	(-0.069)		(-0.637)	(0.337)
DEPHC2	-.511610		1.05210	
	(-0.369)		(0.797)	
SIZE	.676210	.682440	.734900	.749260
	(3.699)	(4.168)	(4.063)	(4.169)
SIZE2	-.005133	-.004912	-.005616	-.005927
	(-2.861)	(-3.169)	(-3.114)	(-3.384)
AVBA	-.399250	-.385470	-.406650	-.397340
	(-2.934)	(-3.032)	(-2.968)	(-2.910)
AVMA	-1.40450	-1.38160	-1.71770	-1.60660
	(-0.720)	(-0.740)	(-0.876)	(-0.824)
AVPHD	-1.67420	-3.74180	-4.88740	-3.70980
	(-0.401)	(-1.191)	(-1.295)	(-1.072)
HC*AVPHD	-1.55410	-.718330		
	(-1.780)	(-1.036)		
HC*SIZE	.006759	-.007368		
	(0.385)	(-0.504)		
HC*DEPHC	2.26170	.919200		
	(3.437)	(3.939)		
INTER-CEPT	-.994860	-3.07880	-1.92830	-4.26180
	(-0.190)	(-0.894)	(-0.366)	(-1.070)
R-SQUARE	.1710	.1550	.1437	.1389
F-STAT	6.789	9.149	7.421	9.217
RSS	107020	109080	110540	111160
d.f.	395	399	398	400
SEE	16.460	16.534	16.665	16.670

Dependent variable: RES(LP4). Figures in brackets are t-stats. Critical t values are: 10% - 1.65; 5% - 1.97; 1% - 2.60.

TABLE A-11: Testing the Sensitivity of OLS Regression Results to Alternate Full and Part Time Enrolment Weights

Variables	Part-time Weight equals 0.0		Part-time Weight equals 0.6	
	Regression	Difference	Regression	Difference
SIZE	.030252 (3.025)	-.000637 (-0.063)	.032557 (3.076)	.001668 (0.164)
SIZE2	-.000250 (-2.536)	.000008 (0.083)	-.000274 (-2.938)	-.000016 (-0.167)
AVBA	-.015066 (-1.863)	-.000417 (-0.053)	-.014084 (-1.884)	.000565 (0.072)
AVMA	-.132870 (-1.020)	-.019930 (-0.172)	-.081747 (-0.888)	.031192 (0.270)
AVPHD	.045750 (0.226)	-.004525 (-0.023)	.050513 (0.281)	.000238 (0.001)
HC*AVPHD	-.155330 (-3.630)	.006290 (0.146)	-.168740 (-3.972)	-.007130 (-0.166)
HC*SIZE	.001603 (1.778)	-.000125 (-0.138)	.001898 (2.091)	.000170 (0.187)
HC*DEPHC	.089938 (6.382)	-.004539 (-0.314)	.103560 (6.748)	.009083 (0.628)
INTER-CEPT	.045128 (0.209)	.019970 (0.093)	-.016160 (-0.077)	-.041318 (-0.194)

The regression columns give the estimated coefficients, and, in brackets, the t-statistics. The difference columns give the difference between the estimated coefficients in the regression column and the estimated coefficients for the OLS regression in Chapter 5. Figures in brackets are the differences divided by estimated standard errors.

TABLE A-12: Testing the Sensitivity of OLS Regression Results to Alternate AVBA Figures for the Universtiy of Toronto

Variables	AVBA at U of T equals 0.5 times Provincial Average		AVBA at U of T equals 1.5 times Provincial Average	
	Regression	Difference	Regression	Difference
SIZE	.033780 (3.171)	.002891 (0.285)	.028211 (2.854)	-.002678 (-0.264)
SIZE2	-.000296 (-2.995)	-.000038 (-0.396)	-.000222 (-2.282)	.000036 (0.375)
AVBA	-.015289 (-1.836)	-.000659 (-0.082)	-.014011 (-1.880)	.000638 (0.081)
AVMA	-.118540 (-1.028)	-.005600 (-0.048)	-.107640 (-0.927)	.005300 (0.046)
AVPHD	.033171 (0.166)	-.017104 (-0.088)	.066308 (0.349)	.016034 (0.082)
HC*AVPHD	-.161600 (-3.762)	.000010 (0.000)	-.161700 (-3.767)	-.000060 (-0.004)
HC*SIZE	.001729 (1.908)	.000001 (0.001)	.001727 (1.907)	-.000001 (-0.001)
HC*DEPHC	.094463 (6.532)	-.000014 (-0.001)	.094524 (6.541)	.000047 (0.003)
INTER-CEPT	.003666 (0.017)	-.021492 (-0.101)	.044459 (0.205)	.019301 (0.090)

The regression columns give the estimated coefficients, and, in brackets, the t-statistics. The difference columns give the difference between the estimated coefficients in the regression column and the estimated coefficients for the OLS regression in Chapter 5. Figures in brackets are the differences divided by estimated standard errors.

TABLE A-13: University-wide Support to Undergraduate Enrolment Ratios

University	Support Catagory		
	Non-faculty support staff	Library acquisitions	Academic Computer expenditures
Brock	.2986	.0372	.0719
Carleton	.4278	.1037	.1153
Guelph	.8060	.1696	.2048
Lakehead	.3933	.1349	.0888
Laurentian	.2278	.0581	.0460
McMaster	.4706	.2135	.1618
Ottawa	.4340	.1189	.1133
Queen's	.4533	.1552	.1870
Toronto	.6112	.1296	.1750
Trent	.2079	.1105	.0285
Waterloo	.4979	.1149	.1626
Western	.5126	.1395	.1621
Wilfrid Laurier	.2992	.1314	.0719
Windsor	.2484	.1340	.1135
York	.4580	.0933	.0715

Source: Committee of Finance Officers_universities of Ontario (1982) "Revenue and Expences of Ontario Universities, 1981-1982" (Toronto: COU)

USIS - UAR system, Management Information Systems Branch, Ministry of Colleges and Universities, Ontario.

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