The Relative Efficiencies of Canadian Universities: A DEA Perspective

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Nous évaluons l'efficacité relative de 45 universités canadiennes à l'aide de la méthode de "data envelopment analysis" (DEA)**.** Les résultats sont obtenus à partir de neufs spécifications différentes des intrants et des extrants. L'efficacité relative des universités est cohérente à travers les différentes spécifications. Un sous-ensemble d'universités — incluant des universités de chacune des trois catégories (enseignement général avec école de médecine, enseignement général sans école de médecine et enseignement au premier cycle universitaire principalement) — est régulièrement jugé efficace et un sous-ensemble plutôt inefficace mais au total, pour la plupart des universités, les niveaux d'efficacité sont relativement élevés. Une simulation de la réduction récente de 20 pourcent dans les subventions provinciales accordées aux universités de l'Alberta montre comment des gains d'efficacité potentiels (tels qu'impliqués et mesurés par cette méthodologie) pourraient se réaliser mais la simulation montre également certaines restrictions. Des techniques de régression sont utilisées en vue d'identifier d'autres déterminants de l'efficacité. Malgré les limites de la méthodologie et des mesures disponibles (sur les extrants principalement) qui font en sorte que les niveaux d'efficacité sont provisoires, cette analyse permet de mieux comprendre la productivité des universités canadiennes et son analyse.

The results of using data envelopment analysis (DEA) to assess the relative efficiency of 45 Canadian universities are reported. Outcomes are obtained from nine different specifications of inputs and outputs. The relative efficiencies are quite consistent across the alternative specifications. A subset of universities — including universities from each of three categories (comprehensive with medical school, comprehensive without medical school, and primarily undergraduate) — are regularly found efficient and a subset quite inefficient but, overall and for most universities, the efficiency scores are relatively high. Simulation of the recent 20-percent cut in provincial grants to the Alberta universities illustrates how potential efficiency improvements (as implied and measured by this methodology) might be realized but it also illustrates certain limitations. Regression analysis is used in an effort to identify further determinants of efficiency. While there are limitations to the methodology and the available (especially output) measures which make the specific efficiency outcomes tentative, this analysis provides insight to university productivity in Canada and its analysis.

Introduction

For many years, Canadian universities have been expected to educate a growing student body, perform research,and meet various public service obligations with diminishing resources, presumably by increasing productivity. Constant dollar government operating grants per student have declined, more or less continually, since the late 1970s and tuition, which has risen in real terms only significantly since the late 1980s, has not been offsetting.[1] The fiscal pressures escalated during the 1990s as federal and provincial governments struggled to eliminate their deficits.

The pressures on universities to use resources more effectively (and to demonstrate that), and the efforts of governments to make universities more accountable and monitor their activities have heightened both the universities' and the governments' interest in performance indicators. While for Canadian higher education, the appeal to performance indicators is relatively new (Bruneau 1994), there has been more experience with them abroad. For example, Johnes and Taylor (1990) and Johnes (1992) write about the UK experience and about indicators more generally. A major problem with performance indicators is that they are a heterogenous, and often a large collection of individual elements which are difficult to translate into a composite and comparable measure of overall performance (e.g., OECD 1987).

The objectives of this paper are to (i) acquaint readers with a methodological tool that can generate a composite indicator of performance; (ii) present results of its application to Canadian universities yielding estimates of university productivity; (iii) illustrate, by reference to recent developments in Alberta, the initial steps toward applications aimed at improving productivity, and (iv) caution readers about the limitations of the data and the methodology. The technique used here is Data Envelopment Analysis (DEA). DEA is a linear programming model/technique that in a multiple input, multiple output situation determines the relative efficiency of the separate decision-making units (DMUs) — universities in this instance. The output of DEA analysis includes information which can be useful in efforts to increase the efficiency of inefficient units. Efficiency scores can also be analyzed, as here, to better understand the causes of relative inefficiency.

DEA analysis is widely utilized for studying the technical efficiency of production units and is especially popular for the investigation of operations in the public sector. Examples include studies of post offices, road maintenance operations, airports, ferries, hospitals, nursing homes and schools among others (Lovell 1993). Institutions of higher education have been studied (both internally and across institutions) with DEA but not extensively (e.g., Ahn *et al.* 1988, 1989; Johnes and Johnes 1995; Sarafoglou and Haynes 1996; Sinuany-Stern *et al.* 1994; Tomkins and Green 1988). We are not aware of any other study of this type using Canadian data. However, Arcelus and Coleman (1995), Jenkins (1991), and van de Panne (1991) each use DEA to examine departmental efficiency within a particular university, while Dickson uses regression analysis to study costs across 61 Canadian universities. As Dickson indicates, there has been relatively little analysis of the costs and productivity of Canadian universities.

We proceed with this paper by outlining next the nature of DEA. The inputs and outputs of universities are then discussed along with the sources of our data. The results of the efficiency analysis for 45 universities in 1992-93 follow. Sensitivity of the results to various features of the model, but especially to variable selection, is addressed. In addition, we review the implications for improving efficiency. The results of a "second stage" regression to explain efficiency scores conclude the analysis. Conclusions and caveats complete the paper.

An Overview of Data Envelopment Analysis

DEA is a mathematical programming procedure developed by Charnes, Cooper and Rhodes (1978) "to measure relative efficiency in situations in which there are multiple inputs and outputs and there is no obvious objective way of aggregating either inputs or outputs into a meaningful index of productive efficiency" (Sexton 1986, p. 100).[2] Productivity depends on the production technology, the efficiency of production, and the production environment. DEA is focused on measuring the second, that is, production efficiency, for each production unit of a set of comparable producing units. Comparability means that the set of producers is producing similar outputs using similar inputs with the same technology. DEA focuses too on productive efficiency to the extent that it can be determined by the decision-makers of the producing unit; hence, the reference to the producing units as decision-making units (DMUs) and DEA's value as a management tool.[3] Productivity can be influenced by factors beyond the DMU's control. For example, differing weather conditions may cause productivity differences among road maintenance crews or among ferry routes. Similarly, the socio-economic backgrounds of students and the demographic characteristics of clients may influence the efficiency measures of schools and health facilities respectively. Such factors are beyond the control of DMUs but may affect relative efficiency. Accounting for such differences is typically handled by introducing them to explain DEA-determined efficiency scores using a second stage regression (Lovell 1993, pp. 53-54).

DEA is used to measure efficiency when there are multiple inputs and outputs and there are no generally acceptable weights for aggregating inputs and aggregating outputs. In the case of one input and one output, the output-input ratio reveals efficiency. If prices exist for all inputs and outputs, the value of outputs to the value of inputs (or indexes of these) can be used. A full set of prices may exist in the case of private firms. In the case of public sector production, prices typically do not exist or do not reflect social values; hence the appeal of DEA for the efficiency analysis of public operations.[4]

The lack of prices means that DEA analysis measures technical efficiency, not economic efficiency. That is, the DEA reveals how efficiently inputs are used to produce outputs but not whether even the efficient units could reduce costs or enhance the value of outputs by choosing different combinations of inputs or outputs. Nevertheless, information on technical efficiency is valuable for assessing and improving the performance of DMUs when price information is lacking or limited.

As a technical analysis, DEA is relative. From the set of DMUs analyzed, it determines an efficient group. It still might be possible, however, to improve the technical efficiency of even those efficient units were the best production possibilities known. However, the actual production function is not known and none is assumed. The efficient units in DEA are the most efficient of those observed, not in comparison to some ideal. Thus, the DEA efficient group is that subset demonstrating the "best practices" among a group of operating units. Inefficient DMUs are compared to those units demonstrating superior performance.

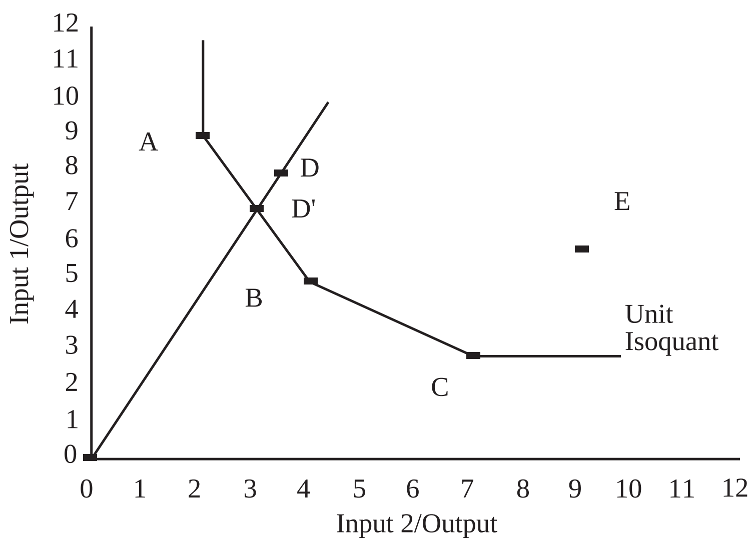
By mathematical programming, DEA finds a weighting system (in the absence of prices) that allows inputs and outputs each to be aggregated and efficiency scores to be calculated. No single set of weights is required. Rather, DEA, by repeated solutions, finds a set of weights for each DMU. The weights are those that are most favourable to the unit; that is, give it the highest efficiency score subject to no weights being negative and that the weights, when applied to any unit, do not result in any one having an efficiency score exceeding 1.0 (on a scale of zero to one with 1.0 indicating an efficient DMU). If the efficiency score of a DMU is less than 1.0, the unit is inefficient. In the simplest case, an efficiency score of 0.9, for example, indicates that the unit could (by following the practices of selected efficient DMUs) reduce each of its inputs by 10 percent and maintain output at its current level.[5] Accomplishing this change would result in that DMU becoming efficient according to the Debreu-Farrell efficiency measure. However, additional (now non-equiproportional) changes to inputs, and possibly even some output change, might improve efficiency further. Also recognizing these possibilities conforms to Koopman's concept of efficiency. While Koopman's approach to efficiency is more stringent and appealing, it is more difficult to measure (Lovell 1993). The DEA method used for this study calculates efficiency measures which proxy Koopman's.

Linked to each programming solution to the DEA efficiency score problem is an equivalent "dual" problem and solution which provides additional information. The dual indicates which of the efficient DMUs each inefficient unit corresponds to most closely (is most like), that is, its reference set, and how a linear combination of those reference DMUs form a hypothetical unit that, if the inefficient unit patterned, would make it efficient. The dual also shows what reductions must be made to each input with output constant (or increases in each output with input constant) to achieve efficiency. Clearly, this is useful information for decisionmakers interested in enhancing a DMU's performance.

A Graphical Depiction

Some of the important concepts of DEA can be most readily illustrated using a simple figure. Figure 1 illustrates a case with five DMUs producing a single output using two inputs. Dividing each DMU's inputs by its output gives the input per unit output combinations which are plotted in the figure. DMUs A, B, and C are technically efficient; they produce a unit of output with the smallest combination of inputs of the group.[6] A piece-wise linear unit isoquant line linking these points forms a convex frontier bounding the observations and tracing out minimal input combinations that will yield a unit of output. The other two units, D and E, lie inside the frontier of best-practice points and are inefficient. If the model is accurate, DMU D, for example, could produce the same output with the input combination D', the intersection of the ray from the origin passing through D and the unit isoquant. It could accomplish this by utilizing its resources in a way representing a mix of DMUs A and B, its reference set. The efficiency of D is equal to the ratio OD'/OD. The reference set for E is DMUs B and C. This depiction is input oriented. A parallel representation could be done for an output orientation.

FIGURE 1
Best Practice Frontier with DEA (Input Orientation)



Scale Economies

DEA can also reveal information about economies of scale. In addition to constant returns to scale (where outputs increase proportionately to inputs), DEA can accommodate variable returns to scale (increasing and/or decreasing returns). While we do not address scale economies in any detail in this paper, we legitimately utilize a variable returns to scale DEA for the analysis.

Limitations of DEA

DEA is a useful analytical tool, but it is important to keep in mind that it has limitations. We highlight only some of the main considerations here but note too that they are not all unique to DEA. All inputs and outputs must be measurable and measured if DEA is to be accurate. In addition, all units of each input and output are assumed to be the same across DMUs. DMUs are expected to be relatively homogenous and employ a common technology to convert inputs to outputs. Because DEA focuses on extreme values, errors in the data may take special significance. Also, DEA can be sensitive to the selection of inputs and outputs. Potential uncertainty over which variables are under decisionmaker control and which are environmental variables can complicate the selection, as well as how each should enter the analysis. Because of the lack of statistical relationships and tests, these latter factors carry added importance. Finally, there is always the question of whether the linear substitutability required for inefficient units to convert to their hypothetical efficient units exits and so the transition would be possible.

Conclusion

Although not without deficiencies, DEA is an attractive and widely utilized method for assessing the efficiency of non-profit institutions like universities. We can therefore anticipate interesting and useful results from this application.

Variables and Data

Variable selection is a most critical part of DEA. Because interest is in efficiency and management performance, the analysis concentrates on variables under the control of the DMU. Environmental variables that may differ among DMUs but are beyond their control are usually introduced, as here, in a subsequent analysis to explain the efficiency scores. Unlike econometrics, DEA has no formal tests to assess the merits of including or excluding variables (or DEA model choice). Instead, one must rely upon the sensitivity of the results to inclusion or exclusion of variables and judgement. Hence, it is advisable to examine the results from a variety of variable specifications to see if DMU efficiency is sensitive to variable selection. The concern for variable selection is compounded by the fact that as the number of variables increases, the number of DMUs deemed efficient and the efficiency scores of the inefficient units will typically increase. Hence, it is particularly important that the variables included should reflect a valuable component of input or output. In addition, it is advisable to keep the number of variables to less than one-third of the number of observations.

The inputs and outputs of universities are generally recognized but, outputs especially, are not easily measured. Universities provide teaching, research, and service. Though various measures of these activities are commonly taken as measures of university output, they are often measures of an intermediate product. In the case of teaching, for example, one would prefer measures of the learning that results from teaching but, instead, measures such as credit hours, student enrolments, and graduates proxy the teaching delivered under the assumption that there is a close relationship between them and learning. Research output is more difficult to measure. Ideally, one would like an index that reflected the quality and impact of the activities undertaken and their products, but no such index exists. Even relatively simple potential components like publication counts are difficult to obtain and are typically incomplete. For example, the publication count variable used by de Groot *et al*. (1991) in their study of the cost structure of US research universities omitted publications from the humanities. Service is the most difficult output to measure. Given the diversity and sometimes even amorphous nature of contributions in this area, there is no composite and reliable index. Studies of university outputs and costs ignore this aspect.

Inputs pose fewer difficulties. Although there are many kinds of inputs — for example, faculty, support staff, student services, libraries, computers, equipment and supplies, maintenance, buildings, etc. — they can usually be defined relatively well in terms of amounts or expenditures. The fact that expenditures can be a relatively complete measure of input and are well documented opens the possibility of studying cost efficiency, an aspect that is also explored in this paper. Variations in input quality, however, may not be easily distinguished. Input prices may vary also but reliable indexes of them are typically unavailable. Capital inputs add another dimension, and one with its own special difficulties. Often there are not good measures of the current capital stock or of its utilization during a period under study. While some analysts have included a measure of capital input (see Ahn *et al*. 1988; 1989; 1993), there is no capital variable in this study.

Output Variables

Our output variables are aimed at measuring teaching and research. Various variables have been employed as measures of teaching output. Full-time equivalent (fte) student enrolment and the number of degrees conferred are the most common; with, at least, a distinction between graduate and undergraduate programs. Student credit hours have been used (Sinuany-Stern *et al*. 1994) but it can have the problem that credit hours can differ significantly among programs of full-time students (e.g., science students with labs versus humanities students) and these differences more likely reflect input differences than learning differences. Bessent *et al*. (1983) use contact hours as an input. Degrees awarded measure completions and a level of accomplishment or extent of learning but they neglect the education of those who attend but do not graduate and do not recognize differences in the length of degree programs (within or across universities), such as between three and four year undergraduate programs, which fte enrolments capture.[7] Enrolments also have an advantage over degrees in allowing for differences in the intake of transfer students from colleges who get advanced placement in the universities.

Rhodes and Southwick (1986; and also Arcelus and Coleman 1995) incorporate both fte enrolments and degrees conferred as output measures in their analysis but are criticized by Ahn *et al*. (1988). In two of their specifications, Ahn and Seiford (1993) include enrolments as input and degrees as output (treating enrolments as an intermediate input into the production of graduates). In their comparison of public and private US universities, they found private universities more efficient under this specification but public universities more efficient when fte enrolments are treated as the output. While they attribute the lower efficiency of public institutions in converting enrolments into degrees to the enrolment-based funding of state universities, it may also have much to do with the differences in tuition between the two and the resulting motivation for students to graduate more quickly from private universities. In their study of university costs, de Groot *et al*. (1991) found the results when using either enrolments or degrees very similar.

We use fte student enrolments for this analysis. There are three major enrolment variables; undergraduates and both master's and doctoral level graduate students. While graduates and undergraduates are usually separated, it is less common to distinguish between master's and doctoral students. However, we feel that these are two quite different products involving different input intensities. Undergraduate students are also subdivided into "science" and "other" students. The science group includes enrolments in science programs, selected health sciences (medicine, dentistry, optometry, and veterinary sciences) and first-entry professional (e.g., engineering) programs. The other group includes those in the arts and social sciences, visual and performing arts, second-entry (e.g., law) professional programs, and unclassified students.

This separation may not be ideal but is what our data allow. Our data do not permit a similar separation for graduate students. Some previous research has found differences in cost or efficiency in the presence of medical schools (de Groot *et al*. and Ahn, Charnes and Cooper) so we explored recognizing separately those enrolled in medicine, dentistry, optometry, and veterinary studies but that distinction never proved important and so is omitted here. The variables are outlined in Table 1.

Research output is especially hard to measure. Lacking reliable and easily obtainable output measures, many studies substitute research grants, an input, as a proxy for research output (e.g., Ahn *et al*.1988; Ahn and Seiford 1993; Rhodes and Southwick 1986; Tomkins and Green 1988 in DEA studies; and Cohn *et al*. 1989 and Dickson 1994 in cost studies). Ahn *et al*. (1989) blend this approach using state funds allocated to state institutions of higher education as input and federal and private research funds as output. Publication counts are sometimes available and used as a measure of research output. Van de Panne (1991) uses this variable alone while Sinuany-Stern *et al*. (1994) and Tomkins and Green (1988) use both publication counts and grants. Sarafoglou and Haynes (1996) use number of articles and a citation impact factor. In their cost analysis, de Groot *et al*. (1991) use publication counts (humanities omitted) as a dependent variable, but also supplement this with graduate program quality ranking based on peer evaluation. Not surprisingly, they find that greater quality implies greater costs.

In this study, because of the lack of better data, sponsored research funds are used as one proxy for research output. We substitute this input for output tentatively and reluctantly knowing that, certainly for many fields (particularly in the fine arts, humanities, and social sciences), the relationship between the two is tenuous at best (Harris 1990; Johnes and Johnes 1995). However, note that for a broad range of sciences, McAllister and Wagner (1981) found a positive linear relationship between research and development expenditures at US colleges and universities and publications. Despite the recognized problems, opting for research funding as a proxy for research output is a common choice.

Quality of research is also a consideration. To proxy research quality, we use a measure of grant support or success — the number of research council grants dispersing funds within the university as a share of faculty eligible for federal research council support. In order to recognize the large differences in the importance and availability of funding between the arts and the sciences, two variables are added here. One is the share awarded the Social Sciences and Humanities Research Council (SSHRC) and Canada Council grants and the other is the share awarded the Natural Sciences and Engineering Research Council and Medical Research Council (NSERC and MRC) grants. Because success of grant applications varies from year to year, a three-year average is taken. This average also helps to offset biases due to year-to-year unevenness in the use of grant funds across universities in the case of grants involving collaborators from different universities. These variables capture the value of grants as recognition for superior scholarship (even in cases where grants might not contribute materially to researcher productivity or reflect the amount of research accomplished).[8]

Input Variables

University inputs are more readily quantified than outputs. Because university inputs must be purchased, expenditures become a feasible aggregate input measure, at least for operations, and this permits the analysis of cost efficiency. However, because there is interest in the efficiency of various specific inputs, several critical inputs are usually included. Faculty are a primary input and are the largest item in university costs. Faculty are typically incorporated in fte numbers or as salary expenses. Sometimes this is expanded to include all instructors; again as numbers (Van de Panne 1991) or costs (Ahn *et al*. 1988). Other separately designated inputs may include support staff (Arcelus and Coleman 1995), library expenditures (Rhodes and Southwick 1986), sometimes certain research costs or student

TABLE 1
DEA Output and Input Variables[1]

Outputs	
UG	total fte undergraduate student enrolment (A)[2]
UG SCI	fte undergraduate enrolment in the sciences — approximated as enrolments in science programs, selected health sciences (medicine, dentistry, optometry, and veterinary sciences) and first-entry (i.e., directly from high school or CEGEP) professional programs (e.g., engineering).[3]
UG OTHER	fte undergraduate enrolment in other than UG SCI programs — e.g., arts and social sciences, visual and performing arts, second-entry (i.e., university prerequisites required) professional programs (e.g., law) and unclassified students.[3]
GRAD	total fte student enrolment in graduate programs (A)
MASTER'S	fte graduate enrolment in master's level programs (A)
DOCTORAL	fte graduate enrolment in doctoral stream programs (A)
RESEARCH$	total sponsored research expenditures (C)
%SSHCC	number of active SSHRC and Canada Council grants as a percentage of eligible faculty (A)[4]
%MRCNSE	number of active MRC and NSERC grants as a percentage of eligible faculty (A)[4]
Inputs	
FACULTY	total number of full-time faculty in the three professorial ranks (A)
FAC SCI	number of full-time faculty eligible for MRC or NSERC grants (A)
FAC OTHER	number of full-time faculty eligible for SSHRC or Canada Council grants (A)
OTHEREXP	total expenditure (as in TOTALEXP below) less faculty salaries and benefits (C)
TOTALEXP	total operating expenditure and sponsored research expenditure (C)[5]

Notes:
[1]Data for 1992-93 (see 4).
[2]A and C indicate AUCC and CAUBO data respectively (or information derived from data there).
[3]Where the sum of UG SCI and UG OTHER does not equal UG, UG is set equal to the larger of the two.
[4]Data averaged over 1992-93, 1993-94, and 1994-95 or as many years as data were available. Lower response rates for 1993-94 and 1994-95 resulted in no data for some universities in these years.
[5]Excluded from total expenditures are ancillary enterprises, special purpose and trust funds, and non-operating plant costs.

input (as previously noted), and plant (Ahn *et al*. 1988; 1989; 1993) or space (Bessent *et al.* 1983). It is not uncommon, however, to combine various other inputs into a single dollar value.

In our most desegregated version, we employ three inputs. Faculty numbers are divided into two groups; (i) those eligible for SSHRC or Canada Council grants and (ii) those eligible for MRC or NSERC grants. This division accomplishes two things. First, it separates two groups that are believed to require, largely because of the laboratory nature of the sciences, different levels of inputs.[9] Second, because both teaching and research outputs will largely parallel the division of the faculty, these categories will help reflect the nature of the universities' outputs. The numbers are of full-time faculty (not fte unfortunately) in the three professorial ranks. Other inputs are represented by a single dollar amount encompassing non-faculty general operating expenditures and sponsored research. Excluded are ancillary enterprises, special purpose and trust funds, and non-operating plant costs.

Two other input specifications are also examined. In one, faculty numbers are aggregated into a single number and used with other expenditures. Finally, to study cost efficiency, a single input, total expenditures (i.e., other expenditures plus faculty salaries), is utilized.[10]

Data

The data cover 45 Canadian universities for 1992-93. The financial information comes from the Canadian Association of University Business Officers (CAUBO). The other information is the same as that collected by *Maclean's* magazine for its annual review of Canadian institutions of higher education. The Association of Universities and Colleges of Canada (AUCC) collects this information from participating universities and distributes the data to them. While more recent data are available, there were notably fewer responses to the *Maclean's* survey in the two following years.

Certain numbers in our data do not match exactly those reported in the AUCC data. We looked for inconsistencies in the data and compared selected variables to Statistics Canada numbers. In the AUCC data, the number of reported fte undergraduates did not always correspond to the sum of the number of fte students in the various programs. Our total of fte undergraduates is the larger of the two. Also, we categorize all graduate students not in doctoral programs as master's students.

The variables and their sources are outlined in Table 1. The average values and the range of the variables are reported in Table 2.

TABLE 2
Descriptive Statistics

Variable	*Mean*	*Minimum*	*Maximum*
Outputs			
UG	11,706.8	1,976	37,304
UG SCI	5,471.5	276.3	18,564.8
UG OTHER	6,235.3	566.7	19,170.0
GRAD	1,602.7	5	7,360
MASTER'S	1,151.4	5	5,525
DOCTORAL	451.2	0	2,877
RESEARCH$[1]	34,201.7	389	166,735
%SSHCC	16.2	2.1	45.3
%MRCNSE	79.8	10.2	147.5
Inputs			
FACULTY	719.6	102	2,380
FAC SCI	375.0	25	1,453
FAC OTHER	344.6	53	938
OTHEREXP[1]	118,232.9	10,728.8	475,352.7
TOTALEXP[1]	180,204.8	20,522.0	698,741.0

Note: [1]Thousands of dollars.

TABLE 3
Alternative Variable Sets

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*2C/3C*[1]	*4C*[1]	*5C*[1]
Output									
Undergraduate Teaching									
UG	X	X	X				X		
UG SCI				X	X	X		X	X
UG OTHER				X	X	X		X	X
Graduate Teaching									
GRAD	X								
MASTER'S		X	X	X	X	X	X	X	X
DOCTORAL		X	X	X	X	X	X	X	X
Research									
RESEARCH$	X	X	X	X	X		X	X	X
%SSHCC					X	X			X
%MRCNSE					X	X			X
Inputs									
Faculty									
FACULTY	X	X							
FAC SCI			X	X	X	X			
FAC OTHER			X	X	X	X			
Other									
OTHEREXP	X	X	X	X	X	X			
Financial Input (only)									
TOTALEXP							X	X	X

Note: [1]Cost specifications: that is, financial expenditure is the only input.

THE DATA ENVELOPMENT ANALYSIS

Data Classification

Maclean's identifies three classes of universities; comprehensive with medical school, comprehensive without medical school, and primarily undergraduate. DEA assumes that the decision-making units being analyzed produce similar outputs using similar inputs and technology. Differences among universities arising from the presence or absence of medical schools, large versus small graduate programs relative to undergraduate programs, and more versus less emphasis on research raises the question of whether it is legitimate to analyze all these universities together. Preliminary analysis indicated that there appeared to be no problems with analyzing the universities as a single group. Applying DEA to each of the three *Maclean's* categories yielded efficiency results parallel to those obtained when the three clusters were combined. For example, units identified as efficient in the analysis of the 45 together were also found to be efficient units when the analysis was done on the three subgroups. Thus, because the results are consistent and the larger grouping offers more opportunity for analysis, the 45 universities are analyzed as a single group. Though the scores are comparable among categories, it is often convenient to discuss the results for the separate categories.

DEA Model Specifications

The results of nine different specifications of the DEA model are reported. We offer this set of results because DEA analysis can be sensitive to the variables included. Here, the consequences of including additional or different variables will be obvious. Model 1 is the most parsimonious specification. It has the fte undergraduate enrolment (UG), the fte graduate student enrolment (GRAD), and the amount of sponsored research (RESEARCH$) as output variables and faculty numbers (FACULTY) and other inputs (OTHEREXP) as input variables. Various alternative and additional variables are introduced to amend this basic model to capture the effect of potentially important factors and/or provide perspectives of interest. The following changes are introduced individually or in combination: (i) graduate students are divided into master's and PhD levels; (ii) faculty are divided into those in the sciences (in the MRC and NSERC disciplines) and those in the social sciences, humanities, and fine arts (the SSHRC and Canada Council disciplines); (iii) undergraduates are divided into those taking science-related programs and all others; (iv) two variables reflecting faculty members' success at getting council grants are added; and finally, (v) all inputs are combined into a single cost variable. Nine specifications are analyzed and the variables comprising each model are shown in Table 3.

Results: By Specification

Model 1 is the basic model.[11] It has five variables; UG, GRAD, RESEARCH$ for outputs and FACULTY and OTHEREXP as inputs. Being the most restricted with respect to variables among the non-cost specifications, it results (as can be seen from Table 4) in relatively few efficient units: 18 of the 45. Efficient universities appear in each of the three *Maclean's* categories. Four of the 15 universities with medical schools are found efficient (McMaster, Montreal, Toronto, and Western) and efficiency scores in that group range from 0.78 to 1.0. Six of the 11 comprehensive universities without medical schools are efficient in this analysis (Concordia, Guelph, UQAM, Trois- Rivière, Windsor, and York) but, among the others, efficiency scores range down to 0.75. Eight of the 19 primarily undergraduate universities have an efficiency score of 1.0 (Bishop's, Brandon, Brock, Mt. Allison, Mt. St. Vincent, Rimouski, Wilfrid Laurier, and Winnipeg) but scores go down to as low as 0.58. Based on average efficiency scores — 0.92, 0.93, and 0.90 — there appears to be little difference in the relative efficiencies among the three categories of universities.

In Model 2, the graduate student variable is divided into master's level and PhD level students (MASTER'S and DOCTORAL). This allows for the possibility that the amount and type of resources needed to educate those two levels of students may differ. This distinction seems important and it has its major impact on the efficiency scores of universities in the two comprehensive university categories. In the with-medical-school group, only one more university (UBC) is rated efficient, but five (Alberta, UBC, Laval, Ottawa, and Queen's) show notable improvement with the average efficiency of the five rising from 0.89 to 0.96. The average efficiency for this category as a whole rose from 0.92 to 0.94. In the without-medical-school category, UNB, Simon Fraser, and Victoria report efficiency gains from 0.04 to 0.07 but no more ranked as efficient. Memorial, however, slipped from 0.77 to 0.61. Among the primarily undergraduate cluster, changes were more modest. Efficiency scores improved for two universities but declined for six. No change exceeded 0.04 and over the eight, the changes averaged 0.021. Over the primarily undergraduate category, average efficiency declined to 0.89 from 0.90. The master's-PhD distinction is maintained in all subsequent models.

The sciences and the arts are not uniformly balanced among universities. To the extent that this

TABLE 4
Efficiency Scores for Canadian Universities Using Alternative Variable Sets

University	*1*	*2*	*3*	*4*	*5*	*6*	*2C/3C*	*4C*	*5C*	*Times Efficient*	*Minimum*	*Maximum*	*Mean*
Comprehensive with Medical School													
1 Alberta	0.78	0.88	0.88	1.0	1.0	1.0	0.85	0.87	1.0	4	0.78	1.0	0.92
2 UBC	0.91	1.0	1.0	1.0	1.0	0.90	1.0	1.0	1.0	7	0.90	1.0	0.98
3 Calgary	0.91	0.91	0.91	0.91	0.91	0.85	0.85	0.85	0.87	0	0.85	0.91	0.89
4 Dalhousie	0.80	0.81	0.79	0.78	0.86	0.78	0.73	0.73	0.76	0	0.73	0.86	0.78
5 Laval	0.92	0.97	0.97	0.97	0.97	0.95	0.90	0.90	0.89	0	0.89	0.97	0.94
6 Manitoba	0.87	0.86	0.89	0.89	0.90	0.89	0.81	0.81	0.79	0	0.79	0.90	0.86
7 McGill	0.94	0.93	1.0	1.0	1.0	1.0	0.93	0.91	1.0	5	0.91	1.0	0.97
8 McMaster	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
9 Montreal	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
10 Ottawa	0.91	0.95	1.0	1.0	1.0	1.0	0.99	1.0	1.0	6	0.91	1.0	0.98
11 Queen's	0.93	0.98	0.98	0.98	1.0	0.93	0.96	0.97	1.0	2	0.93	1.0	0.97
12 Sask.	0.89	0.89	0.89	0.89	0.89	0.76	0.81	0.78	0.83	0	0.76	0.89	0.85
13 Sherbrooke	0.91	0.89	1.0	1.0	1.0	1.0	0.81	0.81	0.76	4	0.76	1.0	0.91
14 Toronto	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
15 Western	1.0	1.0	1.0	1.0	1.0	1.0	0.94	1.0	1.0	8	0.94	1.0	0.99
Average – All	0.92	0.94	0.95	0.96	0.98	0.94	0.91	0.91	0.93	4.2	0.88	0.97	0.94
Avg – Ineff obs	0.89	0.91	0.90	0.90	0.94	0.87	0.87	0.85	0.82	na	na	na	na
# Efficient	4	5	8	9	10	8	4	6	9	na	na	na	na
Comprehensive without Medical School													
16 Concordia	1.0	1.0	1.0	1.0	1.0	1.0	0.93	0.96	0.85	6	0.85	1.0	0.97
17 Guelph	1.0	1.0	1.0	1.0	1.0	1.0	0.96	0.97	1.0	7	0.96	1.0	0.99
18 Memorial	0.77	0.61	0.61	0.65	0.65	0.63	0.58	0.74	0.74	0	0.58	0.77	0.66
19 UNB	0.87	0.91	0.92	1.0	1.0	1.0	0.90	0.96	0.95	3	0.87	1.0	0.95
20 UQAM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0

21 S Fraser	0.84	0.88	1.0	1.0	1.0	1.0	0.97	0.97	1.0	5	0.84	1.0	0.96
22 T Riviere	1.0	1.0	1.0	1.0	1.0	1.0	0.89	0.89	0.92	6	0.89	1.0	0.97
23 Victoria	0.75	0.82	0.94	0.95	1.0	1.0	0.85	0.87	1.0	3	0.75	1.0	0.91
24 Waterloo	0.98	0.98	1.0	1.0	1.0	1.0	0.97	0.97	1.0	5	0.97	1.0	0.99
25 Windsor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
26 York	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
Average – All	0.93	0.93	0.95	0.96	0.97	0.97	0.91	0.94	0.95	5.6	0.88	0.98	0.95
Avg – Ineff obs	0.84	0.84	0.82	0.80	0.65	0.63	0.88	0.92	0.87	na	na	na	na
# Efficient	6	6	8	9	10	10	3	3	7	na	na	na	na
Primarily Undergraduate													
27 Acadia	0.93	0.92	0.92	1.0	1.0	1.0	0.92	0.92	1.0	4	0.92	1.0	0.96
28 Bishop's	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
29 Brandon	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
30 Brock	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
31 Chicoutimi	0.86	0.86	0.89	0.89	0.90	0.84	0.84	0.85	0.84	0	0.84	0.90	0.86
32 Hull	0.79	0.78	0.94	1.0	1.0	1.0	0.71	0.79	0.79	3	0.71	1.0	0.87
33 Lakehead	0.84	0.87	0.88	0.88	1.0	1.0	0.82	0.92	0.91	2	0.82	1.0	0.90
34 Laurentian	0.82	0.82	0.91	0.87	0.86	0.71	0.79	0.81	0.81	0	0.71	0.91	0.82
35 Lethbridge	0.61	0.59	0.51	0.81	1.0	1.0	0.61	0.68	1.0	3	0.51	1.0	0.76
36 Moncton	0.86	0.84	0.85	0.85	0.79	0.74	0.79	0.84	0.83	0	0.74	0.86	0.82
37 Mt Allison	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
38 Mt St Vin	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
39 PEI	0.58	0.58	1.0	1.0	1.0	1.0	0.54	0.55	0.54	4	0.54	1.0	0.75
40 Rimouski	1.0	1.0	1.0	1.0	1.0	1.0	0.99	1.0	1.0	8	0.99	1.0	0.999
41 St Mary's	0.96	0.93	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7	0.93	1.0	0.98
42 St F Xavier	0.87	0.83	0.87	0.85	1.0	1.0	0.90	0.90	1.0	3	0.83	1.0	0.91
43 Trent	0.92	0.93	1.0	1.0	1.0	1.0	0.93	0.93	1.0	5	0.92	1.0	0.97
44 W Laurier	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
45 Winnipeg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9	1.0	1.0	1.0
Average (All)	0.90	0.89	0.93	0.95	0.98	0.96	0.89	0.90	0.92	5.4	0.87	0.98	0.93
Average	0.82	0.81	0.85	0.86	0.85	0.76	0.80	0.82	0.79	na	na	na	na
(Ineff obs)	8	8	11	13	16	16	8	9	13	na	na	na	na

distribution implies differences in both inputs and outputs, it may be important to recognize such variations in assessing efficiency. In Model 3, faculty are divided into two groups, those eligible for MRC and NSERC grants (FAC SCI) and those eligible for SSHRC and Canada Council grants (FAC OTHER). Introducing this distinction adds (relative to Model 2) eight efficient units; three to the with-medical-school cluster, two to the comprehensive without-medical-school group, and three to the primarily undergraduate set. Among those eight, the improvements in the efficiency scores are typically quite substantial. Exceptional, however, is PEI for which the efficiency score increases from 0.58 to 1.0. Among the primarily undergraduate universities, PEI has an exceptionally high share of its faculty in the sciences (69.5 percent). Average efficiency scores among the three clusters (0.93 to 0.95) converge under this specification.

Separating science from other faculty may not capture all the differences due to variations in programs. Model 4 provides the results of including a parallel subdivision (as best the data permit) of students taking science programs (UG SCI) and those taking other programs (UG OTHER). For five universities (Alberta, UNB, Acadia, Hull, and Lethbridge), this distinction proves important and raises efficiency notably. Although Lethbridge did not become efficient, it experienced the largest improvement: from 0.51 to 0.81. A variant of this classification but including those in the visual and performing arts with science students (on the grounds that they too have a large "laboratory" component in their programs which may demand extra inputs) gave similar results but with somewhat lower efficiency scores. Also, some studies have found it important to distinguish between universities having medical programs and those without. That dichotomy was also explored but was found to have almost no impact on the results, even relative to the case where only undergraduates in total is an output.

Considering only two classifications of undergraduates may be insufficient. A previous version of the paper reported on a model that included seven categories of undergraduate programs. Including this number greatly increased the number of efficient universities — from 27 to 40. However, adding variables in DEA increases efficiency scores and increases the probability of a unit being designated efficient. Hence, those results were discounted in the belief that they reflected primarily the inclusion of a large number of variables. Subsequent analysis substantiates that conclusion. The Herfindahl index, widely used in the industrial organization literature, measures concentration (e.g., Curry and George 1983). A single Herfindahl index value was calculated to reflect the degree of a university's specialization across the set of seven undergraduate programs. When this single variable replaced the seven individual variables, the results matched closely those of Model 3 with exactly the same 27 observations of efficient. Furthermore, adding seven randomly generated variables in place of the seven undergraduate program classifications resulted in 41 (rather than 40) universities being reported efficient and, in addition, only eight observations were not identical and only three of those differed substantially. The diversity of programs offered by Canadian universities is not recognized by DEA as an important determinant of relative efficiency. Thus, while distinguishing science and other undergraduates is relevant, further separation (at least with the available data) seems unimportant and possibly misleading.

Model 5 represents an effort to introduce quality of research and of presumably (primarily) graduate education into the analysis. This is done by adding variables reflecting the faculty's success at obtaining council research grants; that is, %SSHCC and %MRCNSE, the number of active research council grants as a share of eligible faculty for both the SSHRC plus Canada Council faculty and for the MRC plus NSERC faculty. Although individual exceptions occur (Dalhousie and Victoria), adding grant success has a quite modest effect on the efficiency scores of the comprehensive universities. Only one more in each category becomes efficient and average scores hardly change. The impact on some of the primarily undergraduate universities is more dramatic. Three more become efficient and the improvements are quite large: Lethbridge from 0.81, St. F. Xavier from 0.85, and Lakehead from 0.88. This result likely indicates that research strength is less evenly distributed among, or given a lower and perhaps less uniform priority at, the primarily undergraduate universities. Even so, we regard this outcome and the inclusion of these variables for this category with considerable caution. That these variables have such a substantial impact on the efficiency scores of these three universities when their overall grant performance is not that dissimilar from that of others within the group and their graduate programs are small raises questions about whether the improvement associated with the grant success variables might mask important inefficiencies. For example, %SSHCC at 18 percent ranks Lakehead (with Acadia) at the top of the primarily undergraduate group and slightly above the 45 university average of 15.3 percent but its %MRCNSE is below the averages of both groups. Is a modest distinction in one or the other area of grant success sufficiently important to university stakeholders to warrant possibly overlooking inefficiencies in teaching (and perhaps research) even if DEA has defined a new efficient point?

Model 6 demonstrates the effect of deleting RESEARCH$, a questionable proxy for research output. Otherwise the specification is as for Model 5 and the results are compared to those results. Removing RESEARCH$ impacts most the comprehensive university with medical schools. Efficiency scores decline for 7 of those 15 universities and 2 lose their efficient status. For some, the drop in the efficiency score is sharp: for example, UBC from 1.0 to 0.90, Queen’s from 1.0 to 0.93, and Saskatchewan from 0.89 to 0.76. The average efficiency of this group declines from 0.98 to 0.94. Interestingly, the results for the comprehensive universities without medical schools are essentially unchanged. Meanwhile, though no more of the primarily undergraduate universities score inefficient due to this change in specification, three have their efficiency scores reduced (Chicoutimi, Laurentian, and Moncton). Though imperfect, RESEARCH$ may not be an output proxy that can be discarded in the absence of better alternatives.

In some instances, it may be more interesting to consider only the dollar value of all inputs rather than physical amounts of various or certain types. To provide insight of this kind, input cost versions of Models 2 and 3 (which are the same when only one input is considered), 4 and 5 are presented: that is, Models 2C/3C, 4C, and 5C. Costs are the sum of operating expenditures and sponsored research outlays. While efficiency scores for a number of the individual universities move down, some improved (e.g., Memorial). Overall, there are fewer efficient units and the average efficiency scores are reduced somewhat relative to the disaggregated input alternatives. Most notable, perhaps, is that two universities that scored as efficient in all previous cases (Concordia and Trois-Rivière) have efficiency scores from 4 to 11 percent lower here. Some universities (e.g., Sherbrooke, PEI) actually fare relatively less well than those two under the cost specification. Clearly, universities that are found efficient using physical measures of faculty inputs need not be cost efficient. This difference is interesting but must be regarded cautiously because it may reflect the lack of a potentially important distinction (though not obvious in the data) between science related and other inputs that is not adequately captured by the output measures.

A summary is deferred until the end of the next topic.

Results: By University Category

It is also interesting to consider how universities comprising a group and even how individual universities performed. The efficiency scores of individual universities are typically relatively high and typically fit within a relatively narrow range. So too for the three categories of universities. The averages of the three categories across all universities and models are high and very similar: 0.94, 0.95, and 0.93. Thus, overall, the results for individual, and so for the whole group, are typically relatively consistent and reasonably insensitive to these specifications.

Among the universities in the with-medical-school group, McMaster, Montreal, and Toronto consistently score as efficient with Western, scoring 1.0 in nine of ten cases, close behind. UBC, McGill, Ottawa, and Queen's consistently achieve high scores with averages of 0.97 or 0.98. Five universities (Calgary, Dalhousie, Laval, Manitoba, and Saskatchewan) are designated inefficient in all models. Dalhousie (at 0.78) actually has the lowest mean efficiency score while Laval (at 0.94) has the highest of these five.

Somewhat more variation is found for the comprehensive without-medical-school group of universities. Memorial consistently scores as inefficient and has, at 0.66, the lowest average score although it did rather better in the cost specifications.[12] No others have an average less than 0.91 (Victoria). UQAM, Windsor, and York are rated as efficient in all cases. Concordia and Trois-Rivière performed well except when expenditure is the sole input.

Several universities among the primarily undergraduate class perform very well. Seven are deemed efficient in all cases — Bishop's, Brandon, Brock, Mt. Allison, Mt. St. Vincent, Wilfrid Laurier, and Winnipeg — while Rimouski has an almost perfect score. Acadia, St. Mary's, and Trent have consistently high scores with means of 0.96 to 0.98. As before, some perform less well. Chicoutimi, Laurentian, and Moncton never rank efficient. Chicoutimi reports a particularly narrow range of efficiency scores, 0.84 to 0.90. Lethbridge's scores are erratic, ranging from 0.51 to 1.0. Other than when grant success variables appear (or when science and non-science students are distinguished), its efficiency score is less than 0.68. Note that Lethbridge ranked twelfth among all universities in the proportion of science grants to eligible faculty (i.e., %MRCNSE). Lakehead and St. F. Xavier are also responsive to the grant success variables but less so than Lethbridge. The efficiency scores of PEI are likewise sensitive to one factor but it is the distinction between science and other faculty. St. Mary's and Trent also respond to the subdivision of the FACULTY variable but not so much as PEI. Especially for a primarily undergraduate university, PEI has (at 0.69) a very high proportion of science faculty. That this distinction is on the input side contributes to PEI not performing well in the cost equations where efficiency is assessed at about 0.55. Interestingly, PEI's efficiency scores in the cost models do not respond to the parallel distinction of science and non-science students: that is, the cost inefficiency appears to be associated with a science faculty/science student imbalance. Acadia, Hull, and Lethbridge demonstrate some efficiency gains as a result of separating science and other students but, of these three, only Hull to the corresponding separation of science and other faculty. Other universities do not show that degree of sensitivity to these or other factors.

In summary, our own expectations and the results of other investigators suggested that specifications 3, 4, and 5 (and their cost variants) are preferred and the results bear this out. Distinguishing between master's and doctoral graduate students, distinguishing between the arts and sciences, and possibly recognizing grant success as an indicator of research quality are important in determining relative efficiency. Among these specifications, we feel that across the full set of universities the results of Model 4 (and the corresponding 4C, probably with an adjustment for science input) deserve the greatest confidence. If one were focusing on comprehensive universities, the variable set of Model 5 is probably preferred. Regardless of the specifications, the relative efficiencies determined are quite robust. In addition, there are universities in all three clusters that are consistently efficient and others that are consistently inefficient. Finding this cross-category distribution supports the decision to analyze all the universities together as a single group. Although the relative outputs, objectives, and priorities differ somewhat among the categories, the outputs and the technologies seem sufficiently similar that all universities can be analyzed together.

Toward Improving Efficiency

Identifying ways to improve performance is an objective of DEA. For universities not on the efficiency frontier, DEA recommends input and/or output changes and identifies universities to possibly emulate. To illustrate the approach, we simulate the impact on the Alberta universities of the 20-percent cut in the provincial government grants which were imposed over three years from 1994-97. Outputs, however, are assumed not to change. The potential consequences of the 20-percent cuts are demonstrated for both Model 4 and its cost version Model 4C. Consider the results for Model 4 first.

Using the results from the pre-cut Model 4 as our reference, Alberta is efficient and Calgary and Lethbridge are 0.91 and 0.81 efficient respectively. A simple interpretation of these latter two scores is that these universities should, by using technologies observed at efficient universities, be able to produce their same outputs with 91 and 81 percent of their existing inputs. We project the impact of the cuts by reducing the inputs in these universities by the amounts necessary to meet a 20-percent decrease in the grants.

Model 4 has three inputs: faculty in the sciences (FAC SCI), other faculty (FAC OTHER), and other inputs (OTHEREXP). The reductions in the respective faculty needed for faculty to bear its share of the cuts are very close to 10.5 percent across the three universities. The percentage reduction is less than 20 percent because provincial grants made up 77 to 79 percent of the university operating revenues and faculties accepted a 5-percent cut in salaries. The residual required to meet the grant reduction was removed from other inputs. This decrease varied from 9.2 percent in Calgary to 13.5 percent in Lethbridge. These reductions do not make any adjustments for the parallel wage reductions accepted by non-academic staff, interim price changes or subsequent changes in other (especially tuition) revenue. While more refined calculations could be made, they may not be more representative and these demonstrate the implications quite well. These assumed changes will not necessarily match the actual changes which occurred because of various short-run strategies that were adopted but, in the absence of further developments, they will approximate the longer-run implications.

The before and after cut efficiency scores are reported in Table 5. Calgary becomes efficient while efficiency at Lethbridge increases from 0.81 to 0.92 under this specification. Alberta continues to score as efficient.

TABLE 5
Alberta Universities: Impact on the Efficiency Scores of a 20-Percent Reduction in Provincial Government Grants

	Efficiency Scores			
	Model 4		*Model 4C*	
University	*Pre-Cut*	*Post-Cut*	*Pre-Cut*	*Post-Cut*
Alberta	1.00	1.00	0.87	1.00
Calgary	0.91	1.00	0.85	0.96
Lethbridge	0.81	0.92	0.68	0.80

Table 6 reports the changes in inputs imposed due to the grant reduction (i.e., to realize the post-cut efficiency score) and also any further changes that would be required to achieve efficiency. It is the latter changes that are of interest here. The imposed cuts result in Calgary being scored efficient (and the full amount of those cuts is required). For Lethbridge to become efficient, not only would all inputs need to be reduced by about one-quarter but outputs also need to be expanded. DEA indicates that undergraduate science-student enrolments could be increased by almost one-fourth, master's enrolments could be expanded from 27 to 555 and even a small PhD program could be established.[13] In Alberta's case, the grant reductions impose cuts of about 10.5 percent in all inputs although the university already ranks as efficient. Hence, for relative efficiency, zero cuts are needed according to the DEA analysis. This situation emphasizes an interesting reservation. Inputs are reduced and outputs maintained under the assumptions of the DEA and the efficiency score does not change. But could Alberta, already on the frontier, actually reduce inputs as projected and maintain the quantities and qualities of its outputs as assumed? Because Alberta is already DEA efficient, there are no other universities which independently or in combination accomplish what is projected for Alberta. That is, the changes due to the cuts assumed here go beyond best-practices experience so there is no evidence of other universities already realizing what is being expected of Alberta after the cuts. This is unlike the Lethbridge case. There, on the basis of performance observed at other universities (notably Wilfrid Laurier, Bishop's, and Mt. St. Vincent) which have input and output structures rather like Lethbridge's, it appears that Lethbridge should be able to actually produce more with less. Consistent with this result is that the data show Lethbridge to have, relative to others in its class, a low student to faculty ratio and high expenditure per student. Even after the increased enrolments required for efficiency, the overall student-faculty ratio at Lethbridge would be 80 percent of the average of its three reference set universities and expenditure per student almost 25 percent higher.

Suppose that universities were not bound by the specific reductions in faculty and non-faculty inputs assumed in Model 4. To see the consequences of a 20-percent grant reduction with full flexibility of inputs, the results for the cost version of the above case, Model 4C, are also reported. Note that under this specification, no Alberta university is assessed as efficient prior to the grant reduction (perhaps due to the inability to distinguish science inputs).

The 20-percent cut in grants implies reductions of 12.2, 11.7, and 14.3 percent in total expenditures at Alberta, Calgary, and Lethbridge respectively.[14] With the grant reduction but outputs unchanged, Alberta's relative efficiency increases from 0.87 to 1.0, Calgary's from 0.85 to 0.96, and Lethbridge's from 0.68 to 0.80 (Table 5). The additional changes needed to achieve relative efficiency differ from those for Model 4. Here, Calgary is called upon to reduce expenditures an extra 1.4 percent to 13.1 percent in total and also expand its graduate program with a 46.4 percent increase in master's enrolments (from 1,654) and a 19.3 percent increase in the doctoral program (Table 6). While this change would represent almost a 40-percent increase in Calgary's graduate enrolment, it would be only a 4.5-percent increase in total enrolment. Lethbridge is again expected to cut expenditure by about one-quarter (28.7 percent) and to increase student numbers. While, again, a small PhD program is indicated, the increase in the master's enrolment is more modest (about six times to 181.6) but the capacity is seen to exist to expand also undergraduate science enrolments by 87.4 percent. The implications of the enrolment changes alone on the student-faculty ratio and on expenditure per student parallel those noted just above for Model 4 which indicated available capacity. Alberta is found to be efficient without changes beyond the 20-percent grant reduction. More important, the 20-percent cut is actually twice what is needed for Alberta to become

TABLE 6
Alberta Universities: Input and Output Changes to Realize Post-20-Percent Grant Reduction Efficiency Scores and Changes to Achieve Full Efficiency

	Alberta		*Calgary*		*Lethbridge*	
	For Post-Cut Score	*For Efficiency*	*For Post-Cut Score*	*For Efficiency*	*For Post-Cut Score*	*For Efficiency*
Model 4						
UG SCI	0	0	0	0	0	+23.2% (637→785)
UG OTHER	0	0	0	0	0	0
MASTERS	0	0	0	0	0	+1965% (27→555)
DOCTORAL	0	0	0	0	0	na (0→33.7)
RESEARCH$	0	0	0	0	0	0
FAC SCI	-10.5%	0%	-10.5%	-10.5%	-10.5%	-26.0%
FAC OTHER	-10.5%	0%	-10.5%	-10.5%	-10.5%	-26.0%
OTHEREXP	-10.6%	0%	-9.2%	-9.2%	-13.5%	-27.6%
Model 4C						
UC SCI	0	0	0	0	0	+87.4% (637→1194)
UG OTHER	0	0	0	0	0	0
MASTERS	0	0	0	+46.4%	0	+572. 6% (27→181.6)
DOCTORAL	0	0	0	+19.3%	0	na (0→14.5)
RESEARCH$	0	0	0	0	0	0
TOTALEXP	-12.2%	-6.1%	-11.7%	-13.1%	-14.3%	-28.7%

Note: Values in parentheses report the absolute change from actual to projected levels.

efficient. Alberta would be efficient with a reduction of only 10 percent in the grant or 6.1 percent of total expenditures. Models 4 and 4C propose a similar pattern but somewhat different specific changes for the three Alberta universities.

As already indicated, universities seeking to improve efficiency have examples to consider. This information results from DEA calculating efficiency for a unit relative to an efficient hypothetical alternative that is a combination of already efficient units (the inefficient unit's reference set) having related input-output characteristics. Under Model 4C, Calgary's reference set is Brock, Montreal, and UQAM. For Lethbridge, Bishop's continues as a major university in the reference set but Winnipeg replaces Mt. St. Vincent and Wilfrid Laurier. Comparison with universities in a DMU's reference set may reveal potential efficiency gains.

Reference sets were also obtained for the other inefficient universities. Although the details are not documented here, we outline the general pattern of the results. All efficient universities do not necessarily appear in reference sets. Model 4 omits eight: McMaster, UQAM, Simon Fraser, Acadia, Brandon, Hull, Mt. Allison, and PEI. On the other hand, some universities are noted as examples many times: Montreal 9 and 17 times in Models 4 and 4C, Rimouski 9 times in Model 4, Winnipeg 12 times in Model 4C. Though frequently called upon, the degree to which a university contributes toward the hypothetical efficient university may be quite modest: for example, Montreal averages only 8.7 percent in Model 4. Many others are to be copied less frequently but are expected to make a larger contribution when included. Comprehensive universities typically appear in the reference set of other comprehensive universities while those for the primarily undergraduate institutions mostly come from within that class. However, some, notably Rimouski in the case of Model 4 and Winnipeg in the case of Model 4C, serve as examples for several universities in all categories. Primarily undergraduate universities appear more often in the reference sets under Model 4C. Beyond, perhaps, Montreal for comprehensive universities interested in cost efficiency, it is difficult to point to any individual universities which can be considered as examples for inefficient universities generally or even for those within a category. Which universities may serve as good examples for an inefficient university are typically specific to each case and can vary with the DEA specification.

Calculations of efficiency gains such as these demand a word of caution. The efficiency improvements are only realized if inputs decline as assumed but outputs do not change or can even be increased while maintaining quality. When the Alberta government reduced grants, enrolments were not to decline. However, universities might maintain total enrolments but shift students toward lower cost programs, thus not keeping output constant. It would be more difficult to determine whether research output or quality (as opposed to the crude proxies used here) or other (unmeasured) outputs changed with the reduction of provincial support and inputs. In addition, the products of the reference universities are assumed to be comparable to those of the inefficient unit. If these assumptions are satisfied, DEA, by comparing inputs and outputs among universities and assessing universities against similar units on the production frontier, offers a potentially realistic and helpful assessment. The difficulty is whether the inputs and outputs are fully identified and adequately measured. Hence, DEA's implications must be examined and assessed carefully and the consequences of acting as suggested thoroughly reviewed in the specific circumstances before proceeding to implement changes.

Scale Efficiency

As implied by the use of the variable returns-to-scale form of the DEA, non-constant returns are present. Examination of the pure scale economies shows that approximately half of the universities in each category are scale efficient. However, the primarily undergraduate universities (with fte student numbers averaging 4,554 versus 19,708 for the comprehensive universities) have, at 0.943, the lowest mean scale efficiency value (in contrast to 0.98 for the comprehensive universities) but the scale efficiency values are not significantly different. Thus, technical, not scale, improvements appear to be the avenue to relative efficiency gains.

Explaining Efficiency Scores

DEA analyzes outputs and inputs to determine relative efficiency but are there other, yet unconsidered, factors that may influence the efficiency with which universities use resources to produce output? To address such questions, analysts frequently seek to explain the efficiency scores obtained from DEA using regression analysis (Lovell 1993). Ideally, DEA analyzes those factors controlled by the decisionmakers of DMUs while the impacts of variables beyond their control, that is, environmental factors, are explained by regression analysis. Unfortunately, the division between management and environmental variables is not always distinct. Generally, however, the actual inputs and outputs belong in the DEA while factors explaining the efficiency with which inputs produce outputs belong in the regression. Because the efficiency scores have a maximum value of 1.0 which a number of DMUs reach, Tobit regression analysis is utilized.[15] To facilitate the Tobit framework, the dependent variable is *in*efficiency rather than efficiency: that is, one minus the efficiency score.

Various factors can be thought of that might affect the (in)efficiency of a university. Proximity to other universities may impose competitive pressures which enhance efficiency. Proximity may also enable specialization or, alternatively, more isolated universities may be obliged to provide a broad range of programs, even if at somewhat higher cost, because of the lack of alternatives for nearby students. The number of university students within 200 kilometres, ENROL200, is used to capture proximity influences. (Definitions of the regression variables are found in Table 7.) Costs may be lower if universities have a larger proportion of continuing students. To allow for this possibility, the undergraduate enrolment per bachelor degree granted, UG/DEG, is included. Part-time students may introduce higher costs or may facilitate the more effective use of resources. To assess these possibilities, PART-TIME, the portion of part-time students is added. Smaller class sizes are often regarded as a means to better education but smaller classes will require more faculty input to teach a given number of students. To allow for variations of this kind, a CLASS SIZE variable, the proportion of third and fourth year classes having less than 26 students, is included. An index of program specialization, H-INDEX, is added because specialization may influence efficiency. Sudden, and especially unexpected, changes in enrolments or funding may impose difficult adjustments and impair efficiency so ENROL CHANGE and FUND CHANGE are included. ENROL200 and FUND CHANGE are clearly environmental variables beyond management control. CLASS SIZE is under management control but is not an input or output though it can influence the efficiency and may affect quality. The other variables range between these in that universities may have some influence over them but that may be limited by their socio-economic environment or government policy.

Total full-time equivalent student enrolment, FTETOTAL, is added as a final variable. Enrolment may be seen as a scale measure and its place here questioned because the DEA has already incorporated and measured efficiency allowing for variable returns to scale. Scale in DEA, however, is multidimensional while enrolment here is a single factor, although it presumably is a major determinant of the DEA scale measure. While enrolment may capture some residual scale effects, its role here is largely as a control variable because factors like program diversity, class size, and possibly others may be size related. Various other potential variables have been explored by us with little success.

The regression results presented here analyze the inefficiency scores of Model 4 and, its cost version,

TABLE 7
Regression Variables

Variable	*Definition*
ENROL200	total student enrolment in universities within 200 kilometres
UG/DEG	undergraduate fte enrolment per undergraduate degree awarded (A)[1]
PART-TIME	part-time student enrolment divided by total student enrolment (A)
CLASS SIZE	the proportion of third and fourth year classes with less than 26 students (A)
%SCIENCE	proportion of full-time faculty eligible for MRC and/or NSERC grants (A)
H-INDEX	Herfindahl index denoting specialization among undergraduate programs (smaller value, more diversity).
ENROL CHANGE	percentage change in total enrolment, 1990-91 to 1992-93 (SC)[2]
FUND CHANGE	percentage change in total revenue, 1989-90 to 1992-93 (CAUBO)
FTETOTAL	total full-time equivalent student enrolment; UG plus GRAD

Notes: [1]A indicates AUCC data.
[2]SC indicates Statistics Canada data source.

Model 4C. Because Model 4C does not distinguish between science and non-science inputs, %SCIENCE, the proportion of faculty eligible to apply for MRC or NSERC grants, is included as an independent variable. In the case of Model 4, only 14 of the 45 universities score as inefficient but, in the 4C case, 27 are inefficient so there is greater variability in that data.

The regression results appear in Table 8. Focus initially on the results for Model 4. ENROL200 has a negative and significant coefficient indicating that inefficiency decreases the larger is nearby enrolment. The reason for this reduction is not certain. However, the inclusion of H-INDEX in the equation controls for the degree of specialization, so greater competition may be an important contributing factor. While H-INDEX did not contribute to the DEA, it has a significant negative coefficient here. This indicates that program specialization reduces inefficiency or that diversity involves some cost. FTETOTAL is both an important explanatory and control variable. For example, without it, H-INDEX is not significantly different from zero. Although there is relatively little difference among efficiency scores or scale efficiencies across the different categories of universities despite size differences, size, as measured by fte enrolments, decreases inefficiency. With one possible exception, the other variables are not important in explaining inefficiency in this case. The possible exception is PART-TIME enrolment. Although not highly correlated with the other variables individually, multi-collinearity may still be a problem. The coefficient of PART-TIME is not significant here although it appears significant in a variety of more parsimonious specifications. Hence, larger part-time enrolment might reduce inefficiency as measured by Model 4.

TABLE 8
Tobit Regression Results[1]

Variable	*Dependent Variable is the Inefficiency Score from:* Model 4	*Model 4C*
ENROL 200	-0.593E-4 (-2.675)**	-0.474E-5 (-1.381)
UG/DEG	0.445 (1.627)	0.239 (1.130)
PART-TIME	-3.277 (-1.316)	-0.186 (-0.108)
CLASS SIZE	-0.370 (-0.111)	-3.235 (-1.663)
H-INDEX	-13.382 (-2.113)**	-3.382 (-1.390)
ENROL CHANGE	-0.056 (-1.417)	-0.048 (-1.470)
FUND CHANGE	0.027 (1.034)	-0.637E-3 (-0.325)
FTE TOTAL	-0.102E-3 (-2.169)**	-0.120E-3 (-3.587)***
% SCIENCE	–	4.484 (2.722)**
CONSTANT	5.555 (1.650)	2.855 (1.240)
Log likelihood	5.099	10.697
Proxy R^2(note 2)	0.584	0.493

Notes: [1]The dependent variable is one minus the DEA efficiency score. Coefficients are the normalized coefficients. The t-statistics are in parentheses. *, **, and *** denote coefficients significantly different from zero at the 10%, 5% and 1% levels respectively.
[2]Squared correlation of the observed and expected values.

The regression results differ somewhat for the Model 4C scores. Again, fte enrolment is an important explanatory and control variable and, as before, larger enrolments contribute to lower inefficiency.[16] Note that %SCIENCE — the portion of the faculty in natural, engineering, and medical sciences — is an added variable here. It is included because, unlike Model 4, there is no distinction in this DEA model on the input side of the potentially different requirements of the sciences. While science student output is distinguished as in Model 4, that may not be sufficient. That suspicion appears correct.

%SCIENCE has a significant positive coefficient indicating that the larger the portion of faculty in the sciences the greater the inefficiency in cost terms: due, we expect, to the higher cost of supporting science faculty. Thus, when comparing efficiencies, it is important to control adequately for the relative size of science programs. No other variables are important in explaining cost inefficiency. The only other coefficient approaching conventional levels of significance is CLASS SIZE. The negative sign on CLASS SIZE is somewhat surprising in that it implies that as the portion of small senior classes increases, inefficiency decreases. This unexpected sign might be explained by various possible interactions, for example, larger junior classes. Notably, neither ENROL200 nor H-INDEX is important in this case, although the coefficients of both have negative signs as before.

These regression equations explain only half or a little more of the inefficiency. This is not necessarily a problem. It may be indicating that the major determinants of efficiency are captured by the DEA variables — that is, environmental variables are not that important. While there certainly is room for improving the measures in the DEA and in the regression analysis, some of the inefficiency may not be explainable by independent elements but result from differences in resource utilization and management at the university level.

Several other variables were considered but found not to explain inefficiency. Variables also examined included variations on the funding change and the enrolment change variables, various levels of funding variables, adjustments for input prices, the presence of medical programs, the share of academic salaries paid to part-time staff, and measures of grant holding.

Conclusions and Caveats

This paper reports on the results of using data envelopment analysis to assess the relative efficiency of 45 Canadian universities using 1992-93 data. Outcomes are obtained from nine different specifications of inputs and outputs. Although specification is important, the relative efficiencies are quite consistent across the alternatives (and especially so across the preferred alternatives). A subset of universities — including universities from each of the three categories (comprehensive with medical school, comprehensive without medical school, and primarily undergraduate) — are regularly found efficient and a subset quite inefficient but, overall, the efficiency scores are relatively high. The average university is about 94 percent efficient but there is a possibility that, due to the modest number of observations, efficiency scores are upwardly biased. Simulations of the recent 20-percent cut in provincial grants to the Alberta universities illustrate, based on the performance of similar universities, potential efficiency improvements as implied and measured by this methodology. Important limitations of the approach are also illustrated by that example. Regression analysis of the (in)efficiency scores is relatively unsuccessful in identifying further determinants of inefficiency. There is some evidence, however, that competition from nearby universities, program specialization and, to a greater extent, total enrolment (although the DEA already allowed for economies of scale) increase efficiency.

The choice of variables included in the DEA is important. It is valuable to distinguish between master's and PhD level graduate students. It is also important to identify separately science and other programs in terms of both inputs and outputs (i.e., faculty and students here). Interesting and important to note is that universities that are input efficient are not always cost efficient although the two results are generally consistent.

While working with commonly used measures of input and output, we are not satisfied with the variables available; especially the output measures. Quantities or numbers of students in undergraduate, master's and PhD programs are measured but not the value added by the teaching and the research training the universities provide. Using sponsored research funding as a proxy for research output is particularly deficient. There is no indication of the value of the scholarly contributions or technological improvements which resulted from the funded research nor any indicator of the amount or value of unfunded research. Success with council grants probably serves as a reasonable index of scholarship but it too must be viewed with considerable caution. There is no measure whatsoever of the public service component of university output. Nor is there any attempt here to account for capital inputs or the specific quantities of other inputs (beyond an aggregated dollar measure) other than faculty. Also, only faculty numbers (usually two types) are used. There is no accounting for possible differences in experience or other quality considerations. In this context, there is a danger that a university that taught large numbers of students, held large amounts of sponsored research funding and had a small faculty would appear efficient and held as a standard to meet even if the students were poorly educated and few scholarly publications resulted. This problem is not a concern here. The academic objectives of universities and their funding governments and agents plus inter-university competition ensure, we believe, comparable standards of teaching and research. However, the lack of good quality as well as quantity measures of output and input limit comparisons among universities and, likely more seriously, comparisons over time, especially when resources are changing.

Despite these caveats, the DEA analysis is helpful. It provides more reliable comparisons than performance indicators. Universities can see their standing relative to their peers and assess their performance and options with the information generated. That supplementary analysis must be done at the individual university level. The universities have the information, insight, and understanding of their operations, inputs, outputs, circumstances, expectations, priorities, etc. that enables them to do those assessments more knowledgably than the simple but fundamental diagnoses resulting from the limited descriptors available to DEA. But it is DEA that, partly by providing comparable rankings, can motivate such assessments plus offer direction by pointing to options and to better performing comparable institutions.

Further DEA could be of added assistance. Improvements might be made by identifying students at all levels by area of study: for example, Canada Council, MRC, NSERC, and SSHRC. Also, it could be useful to analyze more homogeneous units, faculties or departments, across universities. At those levels existing measures may be more meaningful and superior alternative and additional data are likely to be available. Overall, the analysis presented here is an interesting and helpful step toward further study of university productivity in Canada.

Notes

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[1]Provincial government operating grants to Canadian universities per full-time equivalent student averaged (in 1986 dollars) $7,911 in 1980, $6,376 in 1989 and $5,530 in 1995 (CAUT 1996, pp. 12-13).

[2]The discussion in this section draws partly from introductions to DEA available in Ali and Seiford (1993), Banker *et al.* (1989), Lovell (1993), Seiford and Thrall (1990), and Silkman (1986).

[3]Epstein and Henderson (1989) assess DEA as a management tool.

[4]Alternatives to DEA exist. Another non-parametric non-stochastic method, a variation of DEA, is the free disposable hull (FDH) approach. Frontier regression analysis offers a parametric option but is limited to a single dependent variable (e.g., cost). Lovell (1993) discusses both these alternatives. De Borger and Kerstens (1996) compare DEA and FDH in an application.

[5]DEA models may be input or output oriented. This example is written in the input-oriented context. If an output-oriented analysis were done instead, the efficient and inefficient units would remain the same but the

efficiency scores could differ between the two. See Ali and Seiford (1993), for example.

[6]Without prices, it cannot be determined which (if any) of the three technically efficient DMUs are economically efficient.

[7]For community college occupational and technical education programs, Bessent *et al*. (1983) are able to supplement the number of students completing with employer satisfaction scores.

[8]Some provinces have funding agencies the awards of which might be used in a similar way to recognize quality research among the provincial universities. Because such grants are provincial only and not comparable nationally, they are not considered in that way here. However, such funds comprise part of universities' sponsored research funding.

[9]It might be argued that the fine arts should not be combined with the social sciences and humanities but our data do not identify those faculty separately.

[10]Recognizing that input prices can vary, we experimented with some rather imperfect price indexes but abandoned that approach.

[11]Throughout this paper, the reported results are from the application of an input-oriented, variable returns-to-scale version of a DEA program. The output orientation generates similar results. Generally speaking, the efficient units do not change with the orientation although the efficiency scores vary somewhat.

[12]In an earlier version of this paper, the University of Regina was found to have an average efficiency score of 0.57. However, this appeared to result from an anomaly in the reporting of the data. An imperfect adjustment improved the efficiency scores considerably (to as high as 0.89). Because the anomaly could not be overcome successfully, Regina is deleted from this analysis.

[13]Recall that the efficiency scores reported proxy the Koopman's definition of efficiency (i.e., to reflect the potential for any excess inputs to expand output) so the adjustments recommended may involve more than equiproportional input changes.

[14]The percentages exceed those for Model 3 because the 5-percent reduction in faculty salaries moderated the decline in faculty numbers.

[15]See Judge *et al*. (1988) for details.

[16]Though enrolment is an important variable in both of the equations reported here, it was not uniformly important in explaining the inefficiency scores of other models examined.

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