DATA ENVELOPMENT ANALYSIS IN HIGHER EDUCATION

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Abstract

This study investigates the potential of Data Envelopment Analysis (DEA) within a higher education institution in relation to alternative measurement approaches.

The first chapter presents an introduction to the higher education context with discussion of the issues affecting performance measurement. It also contains a brief introduction to DEA.

Chapter Two is a review of the relevant literature. The main themes of the literature are performance measurement in education, the mathematical development of DEA and applications of DEA in numerous contexts with a focus on DEA applications in education.

The theory behind DEA is contained in Chapter Three including an analysis of the type of information produced by DEA and discussion of the strengths and weaknesses of the technique.

Chapter Four presents the research methodology, detailing the approach adopted in applying each of the performance measurement techniques to the academic departments of the University of Glamorgan. This includes the design of an approach for the measurement of the value added to each department's students and methods for measuring the sensitivity of DEA results to model misspecification and error.

The results of the application of the research methodology are detailed in Chapter Five and the final chapter contains an evaluation of the techniques applied using a variety of criteria.

TABLE OF CONTENTS

2. LITERATURE REVIEW Cont.

3. DEA THEORY

List of Tables

List of Figures

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Declaration

This is to certify that neither this thesis, nor any part of it, has been presented, or is being currently submitted, in candidature at any other university.

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(Candidate)

INTRODUCTION

1.1 Aims and Introduction

The aims of this thesis are:-

i. To determine whether the technique of DEA produces any additional information and insights when considered alongside traditional methods of efficiency analysis in higher education, and

ii. To apply DEA to the academic departments of the University of Glamorgan and evaluate the results in conjunction with existing and potential appraisal systems.

This chapter is intended to introduce the issues affecting performance measurement in higher education and give an understanding of the context in which it is applied in this study. The following section considers the background to performance measurement and then the problems of specifying and applying appropriate techniques. The subsequent section presents the hypothesis and how it is to be operationalised. The remaining sections discuss the limitations of the research, and how the remainder of the thesis is structured.

1.2 Performance Measurement in Higher Education

1.2.1 Background

The 1980s saw increasing pressure for more planning and assessment in universities. The report of the Steering Committee for Efficiency Studies in Universities, known as the Jarratt Report (CVCP 1985), emphasised the importance of strategic planning in universities and the need to maximise the effective use of limited resources. A number of reports were produced by the government and higher education bodies such as the Committee for Vice-Chancellors and Principals (CVCP), the Polytechnics and Colleges Funding Council (PCFC) and the Universities Grants Committee (UGC). Among these reports were the 1985 Green Paper "The Development of Higher Education into the 1990s" (Cmnd 9524) which advocated the development of performance indicators, and the 1987 White Paper "Higher Education: Meeting the Challenge" which proposed targets for student numbers and set aims of quality and efficiency in higher education. Tables of statistics and performance indicators were published intermittently by the CVCP and the UGC (later the Universities Funding Council (UFC)). In 1988 legislation was passed, with the 1988 Education Reform Act allowing non-university institutions to become corporate bodies and creating funding councils for all higher education institutions. The reason for the continual encouragement of measurement and evaluation was to create greater accountability and control in higher education. According to Cave, Hanney and Kogan (1991,p20) "The government was thus increasingly determined to ensure that higher education institutions meet objectives determined outside themselves and demonstrate that they had achieved these goals".

Aside from the accountability aspect, a valuable benefit of performance measurement is that it contributes to organisational self-learning. The process of defining appropriate indicators, gathering data and interpreting results can lead to a greater understanding of the range of objectives and individual priorities in an institution and the effectiveness with which those objectives are reached. However, performance measurement is a complex issue and the next section considers the difficulties of creating and implementing an evaluation system in a higher education institution.

1.2.2 Performance Evaluation Issues

The first issue to be addressed is that of definition of objectives. For something to be evaluated, it is necessary to define what it is that is being measured. It is only then that an evaluation or judgement can be made on how effectively an institution, department or unit has performed, and how efficiently it has done so. Romney, Bogen and Micek (1989,p85) state that "Knowing one's objectives and assessing the degree of their achievement constitute the essence of institutional performance assessment." In an higher education institution, however, there is no guarantee of congruency of objectives. Managers of different functions or disciplines have varied priorities according to both their own personal preferences and those dictated by their resources or environment. A course manager or head of department may choose to aim for a smaller output of very highly qualified students as opposed to a much larger throughput of less qualified students. A choice may be made through preference or because of the availability or lack of availability of appropriate resources. A manager may prefer staff to spend more time working on research rather than teaching. As the analysis becomes deeper and more individual, however, the range of opinions and objectives grows. Different views are held on what type and level of teaching or research should be undertaken, what the subject-mix and course content should be, for example.

According to Tavernier (1991,p267), "the traditional teaching and research evaluations should derive their standards and their content more directly from the more general goals of the institution itself." This states quite firmly that the institutional objectives should take precedence over other loyalties as far as evaluation is concerned although perhaps they should be within an overall central government supported direction. Tavernier also gives recommendations for the content of mission statements which are a useful tool in establishing institutional priorities.

Premfors (1986) considered "Basic Units", concentrating on seven questions on their evaluation, and noted that most evaluations are only partial. They are focused on either research or administrative problems, Premfors argued, while some important problems arise from the interaction of the four functions identified by Hermeren (1983). These functions are teaching, research, administrative and social, the social function being considerations such as job security and employee and student welfare.

A second issue in performance evaluation is the question of at what level the evaluation is to take place. It could be an evaluation of individual staff or students, courses, departments, faculties or whole institutions.

The definition and measurement of output is crucial to evaluation at any level of education. Education output cannot be valued easily as there is no specific market that places a value on it as in the case of commodities. The actual number of students or research publications may be used but these can only be aggregated on a subjective basis and even then only certain aspects of higher education will be covered. Johnson (1974) identified the four objectives of higher education as being civilisation, research, information storage and teaching. Of the four functions, research and teaching are more measurable. The civilisation function relates to the contribution of universities to the extension of civilisation. The information storage function is seen by Wagner (1979) to be an input with the dissemination of the information being the output. This dissemination may be part of the teaching or research functions.

The measurement of research is a complex issue which numerous academics and government bodies have attempted to address. In 1993 the Universities Funding Council (UFC) undertook an extensive exercise to assess the amount and quality of research being undertaken in all higher education institutions for the purpose of funding allocations. There are significant problems however in trying to assess such a wide ranging activity. There are a number of indicators which can be used to measure research activity, including:-

1. number of publications;
2. number of citations;
3. number of research students or higher degrees awarded; and
4. research grants.

There are problems with each of these indicators. A tally of the number of publications gives no indication of the size or quality of each one. An article may be 5000 or 2000 words long. It may or may not be in a refereed journal and should different journals be graded according to quality or reputation? An article may be singly or co-authored and the level of input of different authors in a jointly written article may be significantly different. Different subjects have different publishing traditions. A researcher working in Mathematics, say, may publish a two page addenda as an article while a social scientist may publish a 3000 word discussion. Both are perfectly valid forms of output but can not be equated. Other forms of publication need to be taken into account also. An academic may publish a chapter, a whole book or may be the editor. These are very difficult to quantify.
In addition to this it is also necessary to consider over what period the measurement is to take place.

The use of citations is proposed in order to show the contribution of an article to the development of a subject, thus providing a quality index for publications. However, an article may be widely cited because it is in a mainstream area whilst an article of similar quality in a fringe area of research may be very rarely cited. A recently published article will have had less time to be cited and would thus be penalised.

The number of research students is sometimes used as an indicator of the level of research being undertaken. This may be more of a measure of input than output, unless the measure used is the number of research degrees awarded. Even then, there is the difficulty of differentiating between masters and doctoral work and the output of those students not working for higher degrees would not be included.

The fourth possible measure is to use the total amount of research grants awarded. Although research grants are inputs, they are often used as an index of the level of research activity in a department or institution. However, a high level of grant income is not necessarily representative of a high research output.

Other difficulties exist in the measurement of research output, especially where different disciplines are being compared. The reinterpretation of what is already known is a valuable output although it may not be counted as such because it is not producing any new knowledge. This would penalise disciplines such as the humanities, where this form of scholarship is most prevalent.

A further difficulty in research evaluation is the distribution of research activity in the units that are being examined. A large department or faculty may have a low research output overall but the entire output of the unit may be produced by a small number of researchers. Hence the per capita output figures are very low although there may be a few researchers achieving excellence in their field. This can apply to evaluations at all levels whether it is departmental, faculty based or an evaluation of entire institutions.

The fourth output of higher education, teaching, is split by Johnson (1974) into the three outputs of maturation, filtering and human capital.

Maturation is providing students with a suitable environment to broaden the mind and to heighten sensibilities. This is not a measurable output as it relates to an overall experience rather than to achievement.

The filtering hypothesis is that the main purpose of higher education is to screen and filter out those individuals with the greatest potential. If this is the case, the ability to get into higher education may therefore be more important than the higher education itself. This implies that the filtering process is a function and not an output of higher education (Wagner 1977).

The human capital output is based on the notion that higher education equips an individual with particular skills. This gives rise to the concept of value added. Value added is a measure of the difference between a student's ability on entering higher education and their ability when leaving, i.e. it is a measure of the value added to a student by the education process.

The measurement of value added is a complex issue particularly as monetary values cannot be placed on either the inputs or outputs. At entry point, the ideal scenario would be to have an entry profile for all students entering courses in a department/institution. A scoring system could then be applied to this profile and each student would then have a single entry score. In practice, entry profiles are time consuming to construct and assigning numerical values to a student's qualifications and experiences may be extremely subjective. It is possible to assign an entry score based on points score in GCE Advanced level examinations, yet an increasing number of students entering higher education now do so with BTEC Ordinary National Diplomas (OND) or with qualifications such as European Baccalaureates. Mature entrants may not hold traditional qualifications but may have substantial life experience which cannot be quantified. Even with A level qualifications 3 'D' grades holds the same points value as 2 'C's yet some courses may value one more highly than the other. There is also the question of whether any further education qualifications are truly indicative of ability and therefore student quality.

Exit scores present a measurement problem also, even though there is a limited range of qualifications awarded by any particular institution or department. Once again, the ideal situation would be to have a quantified exit profile of all students but the same practical constraints apply as for entry profiles. It is difficult to quantify the difference between a degree with first class honours and one with third class honours. A value added score would also require that qualifications of different types such as first degrees, HNDs and masters degrees can be compared. Is it reasonable to compare a postgraduate student with an undergraduate or diploma student? There may be significant differences, both qualitative, and in the resource required for educating students at different levels. Even comparing bachelors degrees can present difficulties. Some courses may be four years of full-time study and some may be three. Some degrees have an integrated work-experience element. There is some justification for measuring the breadth of a student's experience at university (part of the maturation element) but it is extremely difficult, if at all possible, to quantify.

Another problem to be overcome is accounting for different modes of attendance. In the climate of increasing participation rates in higher education more flexible attendance styles are being offered. A student may attend a course either full or part time or may even be following the course via distance learning packages.

Assuming both entry and exit scores can be obtained there are a number of ways in which the difference can be measured. The PCFC/CNAA publication, The Measurement of Value Added in Higher Education (1990) suggested seven different methods of measuring value added. These were split into what were termed "Index" and "Comparative" methods. In an index method, value added is measured by assigning scores to entry and exit qualifications and comparing the two. An index method, however, may produce a rather arbitrary result as it is entirely dependent on the way in which the score is constructed. The second type of value added indicator, comparative value added, "aims to create a level playing field for assessing educational value by comparing the degree results expected for students with particular entry qualifications with the actual degree results achieved." PCFC/CNAA (1990 p11). The expected result would be empirically based. It means, in effect, that a student achieving the same degree or other exit qualification as expected given his/her entry grades would be allocated a value added score of 100%. This is a less arbitrary method of measuring value added but it relies on the underlying assumption of a relationship between entry and exit qualifications.

The comparison of different disciplines raises various issues, both for measuring value added and for performance measurement in general. Resource requirements across courses are diverse with some disciplines containing a much greater practical element than others and thus needing resources such as laboratories or studios. Some subjects may require more intensive teaching and rely less on student-centred learning. This has implications for class sizes.

Marking traditions vary across disciplines with some courses awarding more higher class degrees than others. Part of this variation is because the marking process in the humanities or social sciences tends to be more compressed than in scientific and engineering disciplines.

Entry levels, when using A level score as an entry indicator, vary considerably across subjects. Some courses are more popular and can thus be more stringent in the selection of new students. This has a significant effect on value added comparisons across departments.

A further difficulty to be considered in the measurement of value added is accounting for wastage rates, different completion times and transfers. Wastage rates relate to those students who withdraw or fail to complete courses. They may be calculated by comparing enrolment figures with the numbers graduating but this would not account for those students who join a course in the second or third year or those who withdraw from a course but transfer to another.

The measurement of teaching output is a complex issue, particularly because of the nature of higher education with its diversity of subjects, course types and modes of attendance. The variety of functions of teaching in higher education complicates the measurement issue further as it is impractical to try and measure the extent of maturation in individual students and hence the true value added to that student by the experience and knowledge gained whilst in higher education.

Stability is a factor which can affect the value of performance evaluation. At the institutional level, the pressure for efficiency and accountability may result in some rationalisation taking place. This could involve mergers of institutions and the reassessment of goals and the strategies for attaining those goals. This would require any performance measurement system to be changed in accordance with new objectives.

Structural changes within an institution may make departmental or faculty level evaluations obsolete unless it is possible for the measurement system to respond to the change in structure quickly enough. For this to be possible, adequate data systems and resources are needed. Changes are also possible at a course level.

Other factors which may affect performance measurement are the availability of data. The more comprehensive the information systems within an institution, the more flexibility there is for the specification of a performance measurement system.

Cost affects the feasibility of performance measurement, and the traditional proviso applies that the benefits must outweigh the cost for evaluation to be worthwhile.

There are political implications associated with a system of evaluation. An evaluation is unlikely to be accepted as valid if it is not understood or is perceived to be unfair. There is some opposition to performance measurement in higher education. According to Gregory (1991,p58) "Some academics believe that it is not possible to subject all of the activities of an academic to quality control and to question".

Even where evaluations are accepted they might not be used appropriately. In a consideration of efficiency in the social welfare agency, Heffernan (1991,p126) noted that "efficiency as a tool and a concept is not so much ignored as it is converted into a political weapon."

1.2.3 Summary

There are a series of questions and issues facing performance measurement in higher education. Firstly, the objectives of higher education need to be defined in order to identify what is to be evaluated. The functions and outputs are diverse and their measurement involves consideration of a series of complex issues such as quantifying research output and the value added to students by the higher education process.

1.3 Data Envelopment Analysis

It has been made apparent that education performance measurement presents numerous problems. In this study, the relatively new technique of Data Envelopment Analysis (DEA) is considered for use in higher education. DEA is a method which incorporates multiple inputs and outputs to produce a single efficiency score for each unit being evaluated. This efficiency score is derived through comparison of each unit with a frontier of best current practice. A fuller description of the method is contained in Chapter Three.

Although DEA is still in its infancy, there has been much discussion of the capabilities of and the potential for the use of the technique. Much of this discussion concerns investigation of its mathematical capabilities with an absence of any recorded ongoing applications of DEA. The focus of this thesis is on the potential for the practical use of DEA in higher education.

1.4 Hypothesis

The hypothesis on which this thesis is based is that Data Envelopment Analysis (DEA) can be used to provide more useful, detailed information on the efficiency of academic departments in a higher education institution than is produced by conventional indicators.

This hypothesis is to be tested by applying DEA to the academic departments of the University of Glamorgan for the academic years 1989/90 and 1990/91. The formulation of the model applied, i.e the input and output variables used, is to be in response to feedback from department managers. The soundness of the DEA results is to be verified by the use of sensitivity analyses. This involves the examination of the effect of both the systematic removal of individual variables and the removal of efficient departments from the analysis.

The DEA results will be examined in conjunction with other methods of evaluation. These methods are regression analysis, income and expenditure accounts, unit costs and departmental ratios. Quantitative and qualitative evaluation will be made of results obtained by all methods in order to ascertain the level and type of information provided by each.

1.5 Delimitations

The practical aspect of the research is confined to the academic departments of the University of Glamorgan (formerly the Polytechnic of Wales) and for the years 1989/90 and 1990/91 only. These delimitations are for reasons of data availability. Whilst the University of Glamorgan, being the sponsoring establishment for this project, allowed ample access to the appropriate data, significant changes to the departmental structure during academic year 1988/89 effectively constrained the application to subsequent years. There was also insufficient data available for academic year 1991/2 at the time of the study, and thus the application was limited to the years mentioned above.

1.6 Organisation of Remainder of Thesis

The structure of the remainder of the thesis is as follows.

Chapter 2: Literature Review
Analysis of the development of the key literature relating to Data Envelopment Analysis and to higher education.
Chapter 3: DEA Theory
Description of the theoretical basis of the DEA technique, the type of information produced and an analysis of its strengths and weaknesses.
Chapter 4: Methodological Approach
Description of the research strategy for the application of DEA and alternative assessment methods to the academic departments of the University of Glamorgan.
Chapter 5: Results
Results obtained from each method.
Chapter 6: Discussion
Discussion and evaluation of the methodology and each assessment method.
Chapter 7: Conclusions

LITERATURE REVIEW

2.1 Introduction

The previous chapter gave some background on performance measurement in higher education and presented the aims and hypothesis for this study. This chapter reviews the relevant literature.

The initial work from which DEA was later derived was that by Farrell (1957) on the measurement of productive efficiency. Farrell noted the difficulties of specification of an efficient production function and proposed that it is better to compare performance with the best actually achieved rather than some unattainable ideal. Charnes, Cooper and Rhodes (1978) presented a linear programming method for the measurement of relative efficiency based on Farrell's ideas. The method was dubbed Data Envelopment Analysis (DEA) and the units of analysis called Decision Making Units (DMUs). According to Charnes et al "our measure is intended to evaluate the accomplishments, or resource conservation possibilities, for every DMU with the resources assigned to it" (1978, p.443). In 1979 Charnes, Cooper and Rhodes published a short communication correcting an oversight in the 1978 article. The refined model required that weights assigned to inputs and outputs be strictly positive rather than merely non-negative as proposed previously. The requirement that all variables should have a positive value, however small, was regarded by the authors as more intuitively appealing. The 1978 model and its correction became known as CCR (after Charnes, Cooper and Rhodes).

The next major development in DEA methodology was presented by Banker, Charnes and Cooper (BCC) in 1984. This was the addition of a further constraint in the CCR model to allow for variable returns to scale. The BCC formulation was intended to "estimate the pure technical efficiency of a DMU at the given scale of operation" (1984, p.1088), achieved by requiring that the weights allocated to DMUs in an inefficient DMU's reference set sum to one.

This is the basic development of DEA although there have been many extensions and investigations into the precise mathematical capabilities of the technique along with a plethora of applications of the various DEA models, both as practical demonstrations of how DEA works, and for illustration of the potential of DEA in different scenarios. The analysis of the DEA literature will, therefore, be split into sections for mathematical development and extension and DEA applications (although in some cases there is some overlap).

2.2 Mathematical Development

2.2.1 General Development

As mentioned in the previous section, one of the major issues to be addressed with DEA was its treatment of DMU scale. Banker (1984) showed that CCR, in addition to productive inefficiencies, also reflects inefficiencies due to divergence from most productive scale size. Banker et al (1984) developed a model which would not discriminate against scale inefficiency through the addition of a single further constraint. The issue of scale was approached again by Maindiratta (1990) with an extension of DEA to enquire whether a task would be better performed by a number of smaller units.

Various different DEA models have been offered. Banker, Charnes, Cooper, Schwartz and Thomas (1989) provides an introduction to CCR, BCC, Additive and Extended Additive models. An Additive model was introduced by Charnes, Cooper, Golany, Seiford and Stutz (1985), and under this model a DMU is only considered efficient if all slacks are zero. This model was extended by Charnes et al (1987) to cope with non-discretionary variables.

Other models that have been developed are the Multiplicative (logarithmic) (Charnes et al (1982)) and cone ratio (Charnes et al (1989)) models. The cone ratio model allows for infinitely many DMUs. The different efficiency characterisations obtained for CCR, BCC, Additive and Multiplicative models are examined in Ahn et al (1988a). All of the models have the same basic condition for efficiency (that the slacks must be zero) but further conditions are required in some. Ahn et al proved that a DMU efficient under CCR will also always be additive efficient.

2.2.2 Weight Restriction

The issue of the weights that DEA applies to variables has stimulated much discussion. Dyson and Thanassoulis (1988) explored the consequences of total weight flexibility and argued that "DEA allows too great a flexibility in the determination of the weights on inputs and outputs when assessing the relative efficiency of a DMU. This can lead to some DMUs being assessed only on a small subset of their inputs and outputs while their remaining inputs and outputs are all but ignored." (1988, p.563). Beasley (1990) highlighted the problem of some variables being virtually ignored and proposed that the approach taken should be to identify a common set of weights for all DMUs then compare the results obtained from this with those obtained from unrestricted DEA. If the difference is significant with any particular DMU this would indicate that the efficiency score achieved by that DMU is dependent on ignoring certain variables. Wong and Beasley (1990) presented a model for restricting weights by incorporating additional inequality constraints in the linear programming formulation (eg. Factor A Weight > 2 * Factor B Weight). This method was applied to research ranking variables in universities (Beasley 1990). In Sexton et al (1986) an extension was proposed in which weights could be restricted. This, along with the computation of cross-efficiencies, was intended to address the problems of DEA's treatment of price efficiency and the dangers of mis-specification of variables. Pettypool and Trout (1988) also presented a formulation for a uniform weight model.

On similar lines, Golany (1988) formulated a DEA model with additional constraints to allow for known relations between certain inputs and outputs with the example of using a previous period's advertising expenditure as an input but restricted to assume less importance in the solution than current advertising expenditure. Banker and Morey (1989) argued that the weights assigned by DEA may not be consistent with a realistic ordering of input and output values and proposed that a modified model could be applied which incorporates judgemental information. Roll et al (1991) restated that the argument for total weight flexibility is that a prominent feature of DEA is the representation of DMUs in the best possible light. They also noted that, at the opposite extreme, for a fair and impartial comparison, the same weight should be given to factors for all units (although it may be argued that defining those weights could never be fair and impartial). An intermediate course was proposed which, the authors acknowledged, may detract from objectivity, but nonetheless might be more consistent with the purposes of efficiency study. Although most studies of the issue of weight flexibility have proposed restriction to at least some extent, Thompson et al (1991) found a measurement model, in which fixed weights were used, to be flawed. This was a model applied to the US Department of Environment. Hence they conclude that fixed weights cast serious doubts on the significance of the efficiency measures made.

2.2.3 DEA and Categorical and Non-Discretionary Variables

DEA has been extended by numerous authors to cope with various areas of difficulty such as the inclusion of environmental data or the recognition of the fact that some variables are not necessarily controllable by DMU managers.

Categorical variables, such as geographical location, for example, are problematic as they are not measured on a continual scale but may simply be a description of some environmental circumstance.

Sexton et al (1991) presented a technique for applying DEA to a set of nonhomogeneous DMUs engaged in pupil transportation. The DMUs in this case had diverse site characteristics. The DEA scores from an initial run were regressed against these site characteristics, and then adjusted accordingly before being used in a further DEA run.

Banker and Morey (1986) extended DEA to allow for categorical variables (without the use of regression as in Sexton et al). This extension of the model relaxes the need to assume all factors are measurable on a continuous scale. However, difficulties arise if the categorical variable is controllable at DMU level.

Banker and Morey (1986), recognising that managers must often deal with inputs which they do not control themselves, developed DEA to cope with these non-discretionary variables. Gathon and Pestieau (1992) in their application of traditional measures of productive efficiency (not DEA) introduced the idea that the measures could well include a component pertaining to the institutional environment faced by firms and thus used autonomy as an environmental (non-discretionary) variable. In the case of the incorporation of categorical variables in the Banker and Morey (1986) article, non-controllability is actually a requirement. Ray (1988) produced an explanation of differences in efficiency by considering differences in non-discretionary inputs.

2.2.4 Further Extensions in DEA

Other developments of DEA have been made. Much of this development has been in the investigation of the mathematical properties and capabilities of DEA. Whilst this is a quite valid output, it does not have any bearing on the application of DEA and is not pursued further in this review.

Some other interesting developments have occurred. Golany (1988) incorporated objectives into the linear programming model in order that it could take account of effectiveness as well as efficiency. This is an important development as it bridges the gap between the subjective and objective worlds.

A very important development for the application of DEA is the use of "window analyses" where a DMU's performance is considered over different successive time periods simultaneously. The reason for the importance of this development is that a greater number of DMUs eases the constraint on the number of variables that can be included. Charnes, Clark, Cooper and Golany (1985) applied this concept to USAF maintenance units to give the model greater discriminatory power (and a greater potential number of variables) because of the effective increase in DMU numbers. Thompson et al (1992), however, question the appropriateness of window analyses stating that their use may mean that structural differences in efficiency over time are not discerned. These structural differences may refer to global efficiency improvements due to advancements in technology, for example.

2.2.5 Computational Aspects

In addition to the extensions to the scope of DEA (and associated criticisms and development), there has been substantial discussion of the computational aspects of DEA. In a short communication following CCR's initial presentation of DEA, the formulation was amended to specify that all variables should have a positive weight or multiplier. Boyd and Fare (1984) suggested that this strict-positivity requirement weakens the model but in a rejoinder to this, Charnes and Cooper (1984) corrected errors in Boyd and Fare's criticism. Issues relating to efficient computational methodology were discussed by Ali (1989,1990) and the importance of efficient and accurate computation was noted. Charnes, Cooper and Thrall (1986a,1990) discussed methods of specifying reference sets for inefficient DMUs. The practical microcomputing aspects of DEA were addressed by Phillips et al (1990) and Dieck-Assad (1986) produced a number of micro-computing codes for various DEA algorithms.

2.2.6 DEA Sensitivity

The sensitivity of DEA results is of interest to potential practitioners, and numerous aspects of sensitivity have been covered. Ahn and Seiford (1989) examined the sensitivity of DEA to model selection, variable selection and the aggregation and disaggregation of inputs and outputs. They concluded that the choice of specific DEA model is an important issue because "if DEA results proved to be sensitive to the model selected for an analysis, the credibility of the results obtained would be seriously weakened" (1989. p.16), although in their study, CCR, BCC, Additive and Multiplicative models all gave the same hypothesis test results. Charnes and Zlobec (1989) found DEA efficiency tests to be stable and stated that the cause of possible discrepancies is in the data generation and not in DEA itself. Charnes and Neralic (1989a, 1989b) studied the sensitivity of CCR for the situation where efficiency is preserved with changes in variables (1989b) and for simultaneous input and output changes (1989a). In a 1990 article the same authors conducted sensitivity analysis for the additive model and in 1992 studied the sensitivity of the additive model further for the specific case of discretionary inputs and outputs. Smith and Mayston (1987) undertook a sensitivity analysis in their application of DEA to London Boroughs. The methods they proposed were the removal of individual variables and the analysis of the effect of removing efficient DMUs. Charnes, Cooper, Lewin, Morey and Rousseau (1985) studied the variations in single outputs which do not affect the status of efficient DMUs and concluded that although the situation where altering the output of one efficient DMU affects the status of all inefficient DMUs would be relatively extreme, it is nevertheless desirable to identify those DMUs which have wide ranging effects. This aspect of sensitivity analysis is of particular interest for any application of DEA.

2.2.7 DEA in Relation to Other Techniques

DEA is a relatively new technique and it is important to understand how it relates to other techniques and their relative strengths and weaknesses.

Greenberg and Nunamaker (1987) sought a compromise between DEA and ratio approaches by including traditionally used performance measures in the DEA model as outputs with the stated advantages being that it will promote practical acceptance of DEA and avoid additional data collection expenses (also aiding acceptability to management).

Seiford and Thrall (1990) summarised the weaknesses of regression. The technique only produces residuals and does not readily yield a summary judgement on efficiency. It fits a function based on average behaviour going through the means of X and Y which, according to Seiford and Thrall, are generally not in the data set. Regression is also influenced by outliers although the authors also acknowledge that DEA may be extremely sensitive to variable selection, model specification and data errors. As far as robustness is concerned, Sengupta and Sfeir (1986) found DEA to be superior to regression. Byrnes et al (1988) in their comparison of abilities of regression and DEA found that being non-parametric, DEA was highly flexible, whilst the econometric techniques used may suffer from having a more inflexible production function. The econometric techniques were found to have the advantage of being able to accommodate noise however. Levitt and Joyce (1987) considered that regression presented the problem that making a precise choice of explanatory variables may be almost arbitrary and variables chosen may have little superiority over those rejected. They drew attention to the distinction between an average production function (as in regression) and those showing the best that can be produced (i.e. frontier methods), it being important when measuring efficiency to be able to relate actual output to maximum achievable, not just the average achieved. Lewin and Minton (1986) stated that "least square estimation methods, while useful in identifying central tendencies (average behaviour), are not particularly useful when the objective is to identify and analyse outliers" (where "outliers" refers to current best practice). (1986, p.521)

Swann (1987) applied three different techniques in comparing differences in product design including DEA. All were found to have problems. Banker et al (1986) compared DEA results with econometric results and found similarities. Bjurek et al (1990) compared three approaches for the analysis of productive efficiency in Swedish Social Insurance offices. Two of the approaches included frontier production functions including Cobb-Douglas. The other approach was DEA. The authors noted that the differences in structural efficiency between specifications are surprisingly small. In 1987 Sengupta established conditions for DEA and frontier production functions (as in Bjurek et al (1990)) to produce the same results. Various technical efficiency measures including DEA were discussed in Fare and Hunsaker (1986) with the conclusion that the choice of measure does affect the efficiency score. Delhausse and Fecher (1992) compared a parametric procedure with DEA in the context of the assessment of the relative performance of insurance companies. The correlation between the two measures was found to be high. Bowen (1990) compared DEA with the Analytic Hierarchy Process (AHP) for site selection for a high-energy laboratory. AHP uses subjective judgements and derives a priority measure for each site. It was found that under certain restrictive conditions, the two methods give the same results. Bowen felt this to be important for bridging the gap between the subjective and objective world and proposed a method for site selection combining both methods with DEA used initially and AHP used to discriminate between DEA efficient sites.

Sexton (1986) considered the methodology of DEA in the context of other procedures. Ratio analysis was seen to be inadequate as several different ratios are required to be interpreted simultaneously, producing a morass of numbers and no clear indication of true efficiency. Regression analysis allows for only one output, measured relative to average, not relative to the best achieved and requires a parametric specification. Although the limitations mentioned for ratio and regression analyses do not apply to DEA, Sexton did note some limitations that do affect DEA. Firstly, all relevant inputs and outputs must be specified and measured. Failure to include any relevant variables will bias the results against efficient performance with that particular variable. Secondly, each unit of a given variable is assumed to be the same (eg. One nursing hour is identical to any other nursing hour). Thirdly, constant returns to scale are assumed if the basic form of DEA is used and finally, weights applied to inputs and outputs cannot be interpreted as values in the economic sense. Hence, although Sexton found DEA to be superior as regards the limitations noted for ratios and regression, the technique still has considerable caveats. Bowlin et al (1985) applied DEA and ratios in a hospital context and, whilst they found ratios to be the worst performer (and the most commonly used technique), they concluded that the different measurement tools could all be used but in various combinations.

As has been demonstrated in the previous paragraph, DEA has been compared to other techniques, both parametric and non-parametric. Although many of the conclusions drawn may be dependent on the context of the studies concerned, many differences have been noted between DEA and other methods. The divide between parametric and non-parametric methods has been established, especially relating to the areas of frontier versus averaging methods and between the free specification of models versus the more subjective pre-specified production function. A free specified model has scope for setting different weightings for the variables included.

2.2.8 Summary of Mathematical Development

There has been much discussion in the area of the extension of DEA's capabilities (such as weight restriction, non-discretionary variables or returns to scale), in the analysis of how DEA treats data and measures efficiency and study of the sensitivity and robustness of the technique. The following section considers the different practical applications of DEA.

2.3 DEA and Performance Measurement

2.3.1 General DEA Applications

There has been a multitude of applications of DEA since its original presentation in 1978. These applications are considered in this section, grouped by the area or type of organisation in which the application is focused. Firstly, however, it is important to examine those publications which address issues specific to the application methodology of DEA.

The most significant contribution to application methodology is Golany and Roll (1989) who offered a complete procedure for the application of DEA to any particular context. The procedure is split into stages for DMU selection, variable selection, choice of model and analysis of results. Desai and Walters (1991) specifically addressed the issue of the presentation of DEA results with a proposed method for graphical presentation. They stated that "DEA remains a technique whose results need reinterpretation before they can be readily grasped and used by decision makers and managers" (1991, p.335).
The DEA applications themselves can be grouped into different types of organisation with the most predominant being health care, military operations, banking and education.

2.3.2 Banking Applications

Banks were identified as suitable for DEA applications, particularly banks with a reasonably large number of individual branches. Sherman and Gold (1985) applied DEA to a bank with 14 branches. Their conclusion on the value of DEA was that it is dependent on a full follow-up analysis by the bank management. Vassiloglou and Giokas (1990) in a similar study included a follow-up discussion re the acceptability of the evaluation and the possibility for model improvement. Increased communication and an exchange of knowledge were found to be a benefit of the application. A five-step application procedure was the basis of the methodology in Oral and Yolalan (1990). The procedure was similar to that of Golany and Roll (1989) with the addition of a further step for the formulation of suggestions. Other bank applications were reported in Parkan (1987), Berg et al (1991) and Rangan et al (1988), although the latter was not strictly DEA.

2.3.3 Health Care Applications

Applications in the health care area are quite varied. One of the earliest studies was Nunamaker's (1983) study of nursing service efficiency. Nunamaker carried out some sensitivity analyses based on reductions in output level of efficient DMUs. DEA was found to be a practical efficiency model deserving further empirical study in health care settings. These further empirical studies cover aspects of health care from health centres to the efficiency of physicians. Sexton et al (1989) examined the efficiency of nursing homes to evaluate the impact of a prospective payment system over time. However, no window analysis was used and efficiency trends were calculated using average efficiency scores for each year. This method may produce an incorrect conclusion on the trends of efficiency in the study unless data for all years is included in a single analysis. An analysis of the value provided by nursing homes was undertaken by Gibbs and Smith (1989). Chilingerian (1989) evaluated physicians using DEA and in 1989, Huang and McLaughlin used DEA for the analysis of rural health care programmes. DEA was felt to be suitable for programmes as heterogeneous as rural health care clinics. Stolp and Hooker (1987) considered health centres in Nicaragua but gave a warning for DEA practitioners - "on a political plane, managers should understand that just because DEA analysis is a fairly sophisticated computer based technique does not mean that the results are "true" or "false". Again, DEA is intended to be used as an attention directing device, not a substitute for intelligent decision making" (1987, p.167). Another empirical application to medical centres was undertaken by Sexton et al (1988). The most common health-care type application is to hospitals and the earliest of these was Sherman (1984). The application was used as a test for DEA and the attributes and limitations of the technique are quite extensively expounded. Banker, Das and Datar (1989) used DEA for the setting of cost standards in hospitals and took the unusual step of setting cost targets at the 90th percentile level in order to provide for the possible effects of outliers and ensure the target is achievable. Other hospital studies were undertaken by Sherman (1988), Register and Bruning (1987), Grosskopf and Valdmanis (1987), Borden (1988) and Valdmanis (1992). A more unusual application of DEA in the health care area was by Capettini et al (1985) who used DEA for setting more equitable reimbursement rates for pharmacies. Although some caveats of DEA were identified, the authors felt that in this particular context the focus on the outcomes rather than the process relieves the government of the burden of developing regulations and ensuring compliance.

2.3.4 Military Applications

One of the earliest military applications was by Lewin and Morey (1981) in which the performance of Navy recruiting districts was evaluated. Charnes, Cooper, Golany, Halek, Klopp, Schmitz and Thomas (1986) considered Army recruitment and advertising. Applications in the military field are generally related to the servicing activities within the organisation. Bowlin (1987) applied DEA to United States Air Force (USAF) maintenance activities and, in an earlier application to the same, Charnes, Clark, Cooper and Golany (1985) were one of the first to use window analysis. Maintenance activities were also the focus of an application by Roll et al (1989). In this, Roll et al suggested the use of a Hierarchical Efficiency Monitoring System (HEMS) in which units are provided with efficiency ratings constructed from various reference sets according to which level of organisation the unit is being compared. This allows inferences to be drawn on the performance of different levels. Bowlin (1989) tested DEA for audit of USAF accounting and finance offices and concluded that DEA has the potential to be a viable tool in this context. Army medical centres were the subject of a study by Charnes, Cooper, Dieck-Assad, Golany and Wiggins (1985).

2.3.5 Transport Applications

The subject of transport has received some attention. Kleinsorge et al (1991) applied DEA to the shipper-carrier partnership and included some qualitative measures in the model. Schefczyk (1992) used DEA to examine the operational performance of airlines, finding DEA to be a usable tool within its methodological limits. Chan and Sueyoshi (1991) also applied DEA to the airline industry but with a strategic management emphasis. Forsund and Hernaes (1990) considered the efficiency of Norwegian ferries and Chang and Kao (1992) used DEA for the measurement of the efficiency of bus firms in Taipei. Chu et al (1992) also used DEA to evaluate bus firms but with models designed to produce different efficiency and effectiveness measures which, the study shows, should be kept separate. The effectiveness measure considered the number of passenger trips in relation to the population density and profile. A transport related study was the application of DEA to the measurement of railroad obsolescence (Adolphson et al (1989)). This study highlights DEA's use of best actual performance with which to compare DMUs in contrast to the "Wisconsin Method" of obsolescence measurement which uses data to create a hypothetical "best of the best".

2.3.6 Electricity Distribution Applications

Electricity distribution was the focus of articles by Hjalmarsson and Veiderpass (1992a, 1992b). Greek electricity distribution was studied by Miliotis (1992) and Texas electric cooperatives in Charnes et al (1989). In the latter two articles DEA was applied with other methods (productivity indexes, econometric methods and ratio analysis). Charnes et al (1989) found DEA outperformed ratio and regression models.

2.3.7 General Applications

Thompson et al (1986) used DEA to evaluate prospective sites for a physics lab using cost, time and environmental impact data. Siting decisions were also addressed by Desai (1990).

There have been numerous "one-off" applications undertaken to illustrate the scope of DEA in a wide variety of contexts. Rhodes (1986) considered national parks with variables such as trail miles. He did note some disadvantages of DEA however, especially regarding the more qualitative aspects of measurement. Charnes et al (1989) applied DEA to Chinese cities. Clarke and Gourdin (1991) evaluated the logistics process finding DEA to be understandable to managers without formal grounding in linear programming or operations research. The insurance industry was the subject for Fecher et al but with DEA alongside parametric approaches. A Kendall Rank-Order correlation was used to compare the approaches and the results correlated highly (0.72) although Miliotis (1992) felt that agreement of rankings cannot be considered entirely satisfactory.

Thanassoulis et al (1987) examined the potential usefulness of DEA for rates departments and highlighted the problem of defining an appropriate variable set which, although not a problem peculiar to DEA is nonetheless a prerequisite for satisfactory use of the technique.

One of the more unusual applications is by Ferrier and Hirschberg who used DEA for the analysis of energy audit data for the comparison of different buildings. The different types of buildings were taken into account and each was evaluated on the basis of its climate control efficiency. Cook et al (1990) applied a bounded (restricted) DEA model to the efficiency of highway maintenance patrols. Elam and Thomas (1989) considered information systems organisations in government noting that two hurdles for DEA are the need for an adequate DMU set and the ability to develop measures for services required. Turner and Depree (1991) assessed the disciplinary processes of the accounting profession in the US but stressed the importance of undertaking a follow through investigation and that consistency and care in information collection are required. Smith (1990) used DEA as an extension of ratio analysis for the purpose of evaluation of financial statements. There were a number of specific difficulties of using DEA in this context however, which relate to the nature of financial statements. These were issues such as matching transactions to the benefits accruing from them, variations in accounting practice and the difficulties of capital measurement.

Other applications that have been undertaken include courts (Lewin et al (1992), Kittelsen and Forsund (1992)), forest districts (Kao and Yong (1992)), machine tool industry (Chengzhong et al (1992)), research and development projects (Oral et al (1991)), software maintenance (Banker et al (1991)), economic planning (Macmillan (1988)) and the selling function (Mahajan (1991)). This list excludes applications in the education field as these are detailed in the following section.

2.4 Education Performance Measurement

The analysis of performance in education presents many difficulties. According to Smith (1990) much is made of the difficulty of interpreting company financial statements but these difficulties are nothing in comparison to problems of presenting and understanding information in the non-trading public sector. Knight (1983) stressed the importance of measuring outputs in schools, as parents and pupils are more interested in output than input. According to Knight, the difficulties of measuring output are that the arithmetic measures are limited and much output is not measurable quantitatively. McGee (1988) considered evaluation and appraisal in schools. The conclusion in this case was that success is judged fundamentally by how well all learners are educated. Evaluation involves agreeing what is to be accepted as evidence and establishing mechanisms to collect and process data with minimum disruption. Wakefield (1988) stated that performance indicators of outcomes have little value if not associated with clearly expressed objectives. The ideal characteristics of performance indicators (PIs) were listed by Jackson (1988). Some of the criteria given are that PIs should be consistent, comparable, clear, controllable and comprehensive.

Wagner (1979) discussed the nature of higher education output, splitting it into outputs of civilisation, research, teaching and information storage. Teaching is split further into the functions of maturation, human capital and higher education as a filter (per Johnson (1974)). Of the three, the human capital function lends itself more easily to measurement giving rise to the concept of value added. The PCFC/CNAA (1990) produced a paper on the measurement of value added, identifying two ways to measure it: the index and comparative methods. Index methods measure the difference between a student's achievement on entering higher education and that when leaving, by assigning an entry and an exit score (based on examination results) and calculating the difference. The comparative method considers a student's exit achievements in relation to that expected, given their entry score. Gallagher (1991, p.27) commented that while the introduction of relativity is an improvement on the absolute value of indexing, the end point of the process is still fairly absolute. This is because it involves plus or minus statements on the class of degree actually achieved relative to that expected. Gallagher also noted that the comparative value added used by PCFC/CNAA (1990) is not truly empirical as CNAA claim because a subjective multiplying factor is applied to exit results.

The output of research is an area where measurement is particularly difficult. Johnes (1988) reviewed the bibliometric techniques for the measurement of research and concluded that without direct measures of staff intelligence, aptitude, experience and enthusiasm, research PIs cannot measure the effectiveness of research effort. Peer-review PIs were critically analysed by Gillett (1989). Bell and Seater (1978) examined publishing performance in economic departments. Hare and Wyatt (1988) studied the factors likely to be of importance for a "research production function". They found that very little is known about the functions which determine the productivity of research.

Tavernier (1991) argued for the extension of teaching and research performance evaluation with the employment of strategic management. Kells (1992) considered the approaches and procedures of evaluation and stressed the importance of the alignment of purpose and means in an evaluation process. McElwee (1992) explored the issues in the development of PIs in higher education suggesting that PIs can help change sterile teaching, concluding that PIs are useful when they demonstrably create a better pedagogical process but are not acceptable for the pursuit of cost-effectiveness irrespective of the qualitative needs of individuals. Cameron (1988) noted that resource decisions for institutions are likely to be based on PIs but that the literature lacks an agreed or dominant methodology. Cameron also remarked that DEA may improve higher education efficiency measures but with much yet to be achieved. The CNAA (1991) sought to establish a framework for the use of PIs in course quality assurance but Kells (1990) saw the proposed use of PIs as flawed with dangers inherent in their crude use (eg simple ranking). Jesson and Mayston (1990) analysed the roles of PIs in secondary education and considered the use of DEA.

In addition to the PIs, many other methods of evaluation have been proposed or used in higher education. Gregory (1991) presented a step-by-step scheme for appraisal of departments and individuals, involving department profiles and assessment teams. Banta et al (1986) described an evaluation system in the University of Tennessee based on peer review and strategic planning while McClain et al (1986) gave a glowing account of an ambitious value-added programme used in Northeast Missouri. The latter two evaluation systems were commented on by Bauer (1986) who identified some impediments to the value-added programme, focusing on the amount of work involved in developing and using such a system and the ethics of maintaining such a comprehensive student register. A variety of other evaluation systems have been proposed. Drenth et al (1986) considered an internal evaluation system stating that "if such a system is operative at institutional level, the issue of external evaluation will lose much of its saliency" (1986, p.56). Talbot and Bordage (1986) reported on an evaluation system based on group discussions. Kells (1986) described the US institutional evaluation system with a view to its application elsewhere. Sizer (1992) advocated a strategic planning type approach involving environmental and resource analysis.

2.5 DEA Applications to Education

2.5.1 Secondary Education Applications

It is easy to understand why DEA became appealing for the evaluation of education, with the dissatisfaction and lack of consistent methodology associated with PIs and the complex nature of outputs in education.

Bessent et al (1982) made one of the earlier applications of DEA to schools. The application was undertaken because of deficiencies in prior methods with their inability to handle multiple outputs. The DEA application encountered problems, however, in obtaining data and in the communication of results to those concerned. Extension of the model to a classroom or pupil level analysis was considered. Mayston and Jesson (1991) recognised the need for DEA in schools following the trend towards more devolved financial management in UK schools. Jesson et al (1987) applied DEA to English LEAs but felt the DEA method was limited by inadequacy of data, a major hurdle as data problems concerning educational outputs are not easily overcome. The Department of Education and Science (DES) (1988) outlined DEA and applied it to London schools. Some robustness checks were carried out including removing highly efficient DMUs from the analysis. DEA was considered by the DES to be one possible way forward. Other applications to schools were undertaken by Mayston and Jesson (1988), Bessent and Bessent (1980) and Bessent et al (1984). Diamond and Medewitz (1990) used DEA to evaluate an education programme in schools. Woodhouse and Goldstein (1988) used a multi-level modelling procedure (not DEA, but multi variable) and criticised the use of aggregate level analysis of examination results to assess schools. Boardman et al (1977) used simultaneous equations to model the educational process. Although this was not a DEA application Boardman et al stressed the importance of a student's background (hence the need for an environmental variable).

2.5.2 Higher Education Applications

Little attention has been given to further education applications, but higher education has been studied quite extensively. Bessent et al (1983) produced one of the first applications in the higher education field. Their study used DEA for the evaluation of proposed course programmes. Sarafoglou and Haynes (1990) examined the efficiency of higher education institutions performing building sector research, remarking on the extensive variety and range of research outputs. Ahn et al (1989) evaluated higher education institutions with a view to rationalisation. Individual science fields were analysed in Stough (1991) at both institutional and department level. Ahn et al (1988b) used the CCR model in universities to examine how DEA could be used in higher education as an alternative to more traditional approaches.

All of the higher education applications mentioned so far have concentrated on either whole institutions, course programmes or individual science fields. The following applications are the most pertinent to the present study as they focus on department level analysis. Gadenne and Cameron (1991) applied DEA to accounting departments in Australian universities. A similar study was carried out in the UK by Tomkins and Green (1988). In their analysis, Tomkins and Green stated that "if DEA is to gain widespread use it must be seen as an aid to human analysis and not as a mechanically correct scorekeeper" (1988, p11). Beasley (1990) applied a weight restricted model to physics and chemistry departments. The weight restriction was to allow for different research categories to be taken into account. Jenkins (1991) actually applied DEA to departments within a single university and also used some weight restriction in the model applied.

Apart from Jenkins (1991), no authors have applied DEA to the academic departments in a single university. None of the higher education applications include any form of value added measure or use a student entry level indicator as an environmental input. The only variables included to take student achievement into account are simply numbers of graduates at particular grades. This does not take into account the quality of input or the educational distance travelled by each student in obtaining their qualifications. A fuller DEA application within a single institution is needed taking into account the full range of outputs of higher education but with due regard to the quality of the "material" used.

2.6 Summary

DEA is a complex technique that can be applied to a broad range of settings. It does however have limitations as well as strengths. Stolp (1990) advocates a pragmatic approach to the technique. The main literature has been reviewed covering the principal mathematical development and extensions. DEA is a non-parametric technique and its relative strengths and weaknesses have been compared with more traditionally used parametric measures such as regression analysis as well as such techniques as ratio analysis.

The different application areas have been detailed with a focus on issues in education, particularly higher education. It is in the area of higher education applications that the scope and need for this study has been identified - to apply DEA to the academic departments of a single university taking into account all relevant inputs and outputs including a value added measure, not previously used in a DEA application.

The following chapter will focus on explanation of the theory behind DEA.

DEA THEORY

3.1 Introduction

The previous chapter considered the literature relevant to this study. This chapter focuses on the theory behind DEA. The first section describes what DEA is and how it measures efficiency. The subsequent section is a description of the sort of information that can be produced by DEA and the final part of this chapter considers the merits and weaknesses of DEA and its use.

3.2 What DEA Is

Data Envelopment Analysis (DEA) is a linear programming related technique which measures the efficiency of comparable decision making units (DMU's). These can be either departments or branches within an organisation or separate institutions such as hospitals within a district. DEA uses multiple inputs and outputs, outputs being products or services produced and inputs being the resources used to produce these outputs, plus other environmental factors (such as quality of students in a school for example).

Other methods of measurement such as unit cost data or staff student ratios are restricted to single inputs and outputs and cannot deal with environmental issues. This can lead to a proliferation of indicators whereas DEA produces a single efficiency score.

The DEA model was developed by Charnes, Cooper and Rhodes (1978) based on Farrell's (1957) definition of efficiency. It is not a measure of absolute efficiency as that is impossible to quantify. What DEA records is the performance of each DMU relative to all other DMUs in the set. Therefore, it is an empirically based model. When a DMU is recorded as inefficient, this is by comparison with the actual performance of other DMUs and not in comparison with any hypothetical definition of efficiency. Several different models have been devised which are all based on the principle of Pareto optimality. For a DMU to be inefficient this requires that another DMU or combination of DMUs can produce the same output with less inputs. With DEA, each DMU is given an efficiency score based on the ratio of outputs to inputs so that a relatively efficient DMU will have a score of one.

DMU	Input	Outputs	
	X1	Y1	Y2
A	10	21	90
B	10	28	71
C	10	48	87
D	10	51	57
E	10	73	74
F	10	82	38
G	10	93	52
H	10	105	26

Table 3.1 Example DEA Data

The simplest method to explain DEA's use of relative efficiency is through graphical analysis. Take a situation with 8 DMUs (A-H), 2 outputs (Y1, Y2) and 1 input (X1). The data is contained in table 3.1. The data can then be plotted on a graph with Y1/X1 against Y2/X1. This graph is shown in figure 3.1. The closer to the origin that a DMU is plotted the less efficient it is. An efficiency frontier can be drawn through DMUs A,C,E,G and H (figure 3.2) as none of these DMUs are dominated by any other whereas DMU C produces more Y2 per unit of X than DMU D and DMU E produces more of both Y1 and Y2 per unit than D. Therefore DMU E is said to dominate DMU D. In being allocated an efficiency score DMU D would be compared with a hypothetical DMU Z which is created from a theoretical combination of both DMUs C and E. DMU D is said to be enveloped by DMUs C and E. The efficiency of DMU D can be written as OD/OZ. Thus the efficient production surface is defined by DMUs A,C,E,G and H and all other DMUs are evaluated relative to it.

The graphical analysis obviously limits the number of inputs and outputs that can be used but the principle of relative efficiency is adequately explained. In actual applications of DEA many more variables can be used (although there are still practical limits as mentioned later).

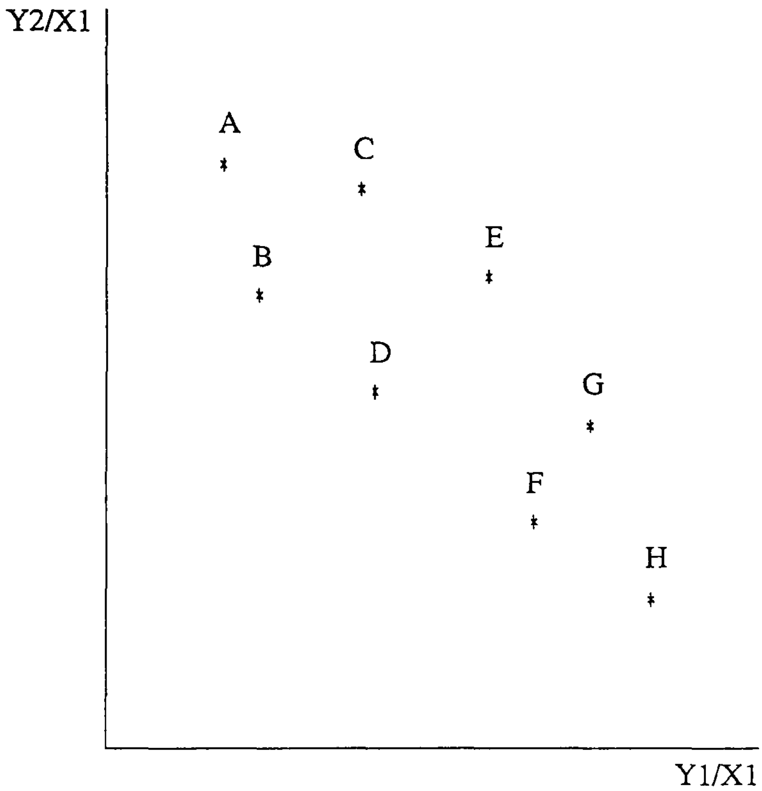

Figure 3.1 Plot of Input/Output Relationships

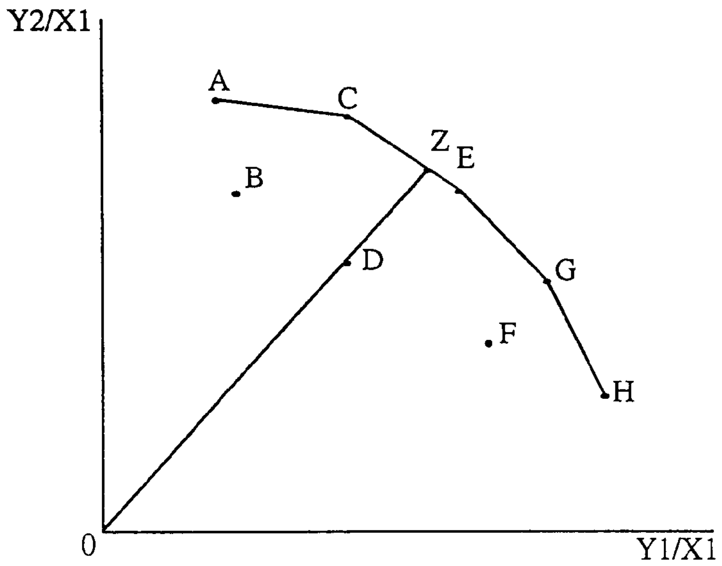

Figure 3.2 Illustration of DEA

The efficiency measure produced by DEA is a bounded measure with a range from zero to one where one represents relative efficiency. The efficiency score is obtained by comparing the weighted average of inputs with the weighted average of outputs. The weights applied to each variable in producing that efficiency measure are not decided in advance but are set by DEA with a different set of weights assigned to each DMU. They are, therefore, set completely objectively. The weights are set in such a way that the DMU in question displays the highest level of efficiency possible. The model promotes a focus on the most favourable input-output relationships for each DMU ensuring that it is seen in the "best possible light". These weights are applied with the restriction however that when the same weights are applied to any other DMU , they cannot produce a score of more than one in any case. There is a further condition that all weights must be greater than zero which ensures they all have at least some impact. A more formal description of the model and its constraints is shown in Appendix A on page 193.

The information generated by the DEA programme will show the efficiency rating and, if that is less than one, the reference set (DMUs) in comparison to which the target DMU is said to be inefficient. In addition, the increase in outputs that would be required to make the DMU efficient can be shown. This assumes an output augmenting approach, as in the graphical analysis. It is also possible to adopt an input conserving approach (See figure 3.3) in which inefficiency would be evaluated in terms of decreases in input possible with constant outputs. In figure 3.3, the efficiency score of DMU G would be expressed as OZ/OG.

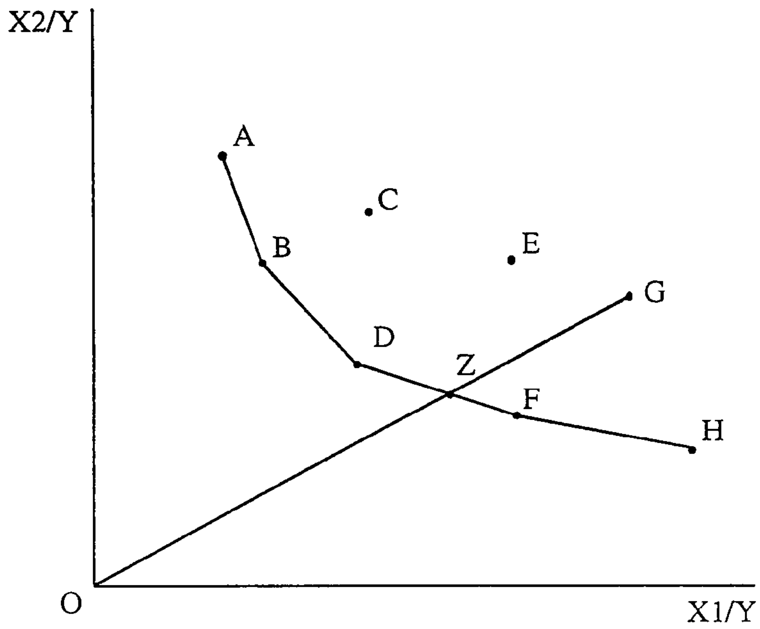

Figure 3.3 Input Conserving Approach

3.3 Results Produced by DEA

DEA produces quite detailed results for each DMU. An example of the type of results produced is shown in the template in figure 3.4. The weights applied to each variable in obtaining an efficiency score are shown. These weights are set by DEA itself and they show which variables have the greatest emphasis placed on them for each DMU. These weights are sometimes known as multipliers or prices although it must be stressed that they are different from the shadow prices produced in conventional linear programming and are not related to any opportunity costs.

DMU: A

Efficiency Score: 0.80 Scaling Factor: 1.25

Outputs	Observed	Projected	Slack	Weight
Y1	144	180	0	12.00
Y2	1200	1600	100	1.00
Y3	220	300	25	1.00
Inputs	**Observed**	**Projected**	**Excess**	**Weight**
X1	20	18	2	1.00
X2	100	100	0	120.50

Reference Set

Department	Weight
B	0.4
D	0.3
E	0.5

Figure 3.4 Individual DEA Results Template

The efficiency scores produced by DEA give a rating of between 0 and 1. DMUs reported as efficient may be differentiated between by virtue of the number of times each are referred to in the reference sets of inefficient DMUs.

The DMUs with which an inefficient DMU is compared are shown in its reference set (at the base of the template). This reference set consists of a number of efficient DMUs with a weighting applied to each. It is used to calculate the projected efficient values for the variables of the inefficient DMU being evaluated. The condition for a DMU being part of the reference set are that the prices applied to the variables for the DMU in the analysis should produce an efficiency score of one when applied to the DMUs in its reference set. This reference set is said to envelope the DMU being analysed. The projected profile for the inefficient DMU is thus a weighted combination of the performance of the DMUs enveloping it. Figure 3.5 shows the calculation of a projected efficient value for a hypothetical DMU A via its reference set.

Department being evaluated: A

Reference Department	Result for Variable Y1	Weight	Weighted Variable
B	200	0.4	80
D	100	0.3	30
E	140	0.5	70
	Projected Efficient Value for Variable Y1		180

Figure 3.5 Projected Efficient Value Calculation

The same procedure is applied to all variables, thus producing the detail in the projected results column of the template. The efficiency score for each DMU is calculated by comparing the observed and projected values for each output variable. The proportional increase required to achieve the projected output is calculated for all outputs. The efficiency score is defined as being the reciprocal of the lowest of these factors. This is illustrated in figure 3.6.

Output Variable	Observed	Projected	Factor
Y1	144	180	1.25
Y2	1200	1600	1.33
Y3	220	300	1.36
Hence Efficiency Score	=	1/1.25 =	0.80

Figure 3.6 Calculation of Efficiency Score

The lowest factor is 1.25 and any additional increase required to meet the efficient values is recorded as slack.

The results illustrated above are all geared to an output-oriented model. There are a number of different configurations of DEA that can be used to analyse any particular data set. Quite different results can be produced depending on which configuration is chosen. When defining models there are two principle choices to be made. Firstly, the orientation of the model, being either input or output orientation and, secondly, whether the model should include assumptions of constant or variable returns to scale.

The orientation prescribes how a decision making unit's (DMU's) efficiency or inefficiency is reported. An input oriented model would present inefficiency in terms of decreases in input required to achieve projected efficient values whilst an output oriented model presents inefficiency in terms of potential increases in output.

DEA can produce a range of efficiency scores for each DMU. In an output oriented model, the efficiency score is the reciprocal of the proportionate increase required in each output to attain the projected values, although some outputs will require further increases also. The input oriented efficiency score shows the projected inputs as a proportion of actual input. Again, some inputs may require further decreases.

Both input and output oriented models may show what is termed "slack" in their outputs and input "excess". Output slack in an output oriented model is the increase required in particular outputs beyond that which is apparent from the efficiency score. Input excess in the same model is the difference between observed and projected values. For example:-

DMU A Output Oriented Model

Efficiency Score 0.80 Scaling Factor 1.25

Output	Observed	Scaled Value	Slack	Projected Value
Y1	144	180	0	180
Y2	1200	1500	100	1600
Y3	220	275	25	300

Inputs	Observed	Excess	Projected Value
X1	20	2	18
X2	100	0	100

Figure 3.7 Illustration of Slack

For an input oriented model, slack in output would be the difference between observed and projected values and the input excess would be additional decreases in inputs required beyond that prescribed by the efficiency score.

DEA can also take into account variable returns to scale if these are believed to exist. However, the basic DEA model makes an assumption of constant returns to scale. The effect of this is that a DMU operating at an extremely large scale may be considered inefficient as compared to a projection of much smaller DMUs or vice versa. It is important therefore to decide whether this would be an equitable comparison to make or whether variable returns to scale exist for the DMU set. The results produced will reflect this choice.

3.4 Strengths and Weaknesses of DEA

DEA has a number of features and strengths which differentiate it from other performance measures as well as a number of weaknesses. These are listed below.

3.4.1 Strengths

1. Use of Multiple Inputs and Outputs.

DEA has the capacity to include both multiple inputs and outputs in producing an efficiency score whereas multivariate regression is restricted to multiple inputs only. These multiple variables are used to produce a single summary measure of between 0 and 1. The potential number of variables is only restricted by the number of units in the analysis.

2. No Assessment of Relative Importance of Weightings is Required.

There is no need for an a priori set of weights to be allocated to each input and output as the weights for each variable are decided mathematically by the DEA programme. This allows every DMU to be viewed in the "best possible light" (Jesson 1988, p.13). If pre-set weights or restrictions are required, however, they can be incorporated into the programme.

3. Comparisons are with Current Best Practice.

"DEA locates technical or pareto inefficiencies in a manner more consistent with economic theory than econometric regression techniques" (Sherman 1984, p.932). This is because DEA evaluates DMUs relative to a "best practice frontier", i.e. what is actually achieved, rather than with a hypothetical frontier or an average function. The advantages of this are that:-

i. it is a practical method of defining efficiency;

ii. DMUs identified as inefficient are strictly and demonstrably inefficient;

iii. no arbitrary cut-off point need be chosen for a unit to be defined as efficient. With regression, a decision rule is needed to define efficiency. For example efficiency could be defined as being on the regression line, or perhaps, one standard deviation above. With DEA, no decision rule is required. A DMU either is or is not on the efficient frontier; and

iv. efficiency is practically and demonstrably attainable.

4. Location of Inefficiency.
DEA identifies the general magnitude of inefficiency and the results projected are just one of many ways in which a DMU can attain efficiency.

5. Non-Controllable Variables May be Used.
All variables entered need not be within the control of the management of the DMU. Also DEA's ability to account for non-controllable variables allows the use of environmental inputs, such as the population served by a pharmacy (Capettini, Dittman, Morey (1985)).

6. Use of Non-Commensurate Inputs and Outputs.
Inputs and outputs can be used as originally recorded. It is not necessary to convert variables into a common base. For example, in an application of DEA to teaching hospitals, Sherman (1986) employed measures as diverse as time measurement, financial variables and staff numbers. There is no restriction on the basis by which each input or output is measured provided that the same basis is used for each DMU. In other words, there is no requirement to standardise variables.

7. Use of DEA for Projections.
The technique need not be used solely ex post but can be used to evaluate proposed changes and enhancements by

including projected data. Bessent et al (1983) used DEA to evaluate proposed changes to course programmes in a college by inputting the projected data into the model. This was in order for decisions to be made on which courses were to be changed or cut. This approach could be used in a variety of circumstances where there are several choices of courses of action, the effect of each of which can be estimated in advance.

8. DEA is a Replicable Quantitative Measure.
The data used is of a numerical nature. The outcomes are thus definitive and can be easily replicated if verification is required.

9. Changes in Efficiency can be Monitored Over Time.
DEA can monitor changing levels of efficiency either for one particular DMU or for the whole field. This can be done by including data for each DMU relating to a number of different time periods simultaneously. This involves including data for every DMU in the analysis once for each time period, allowing comparisons between periods to be made

3.4.2 Weaknesses

1. Effectiveness is not Measured.
In performance measurement the three areas of efficiency, economy and effectiveness are often referred to. Of these, DEA addresses efficiency and, with the inclusion of monetary factors, economy. Effectiveness can be defined as the achievement of objectives. This is not specifically measured by DEA.

2. Techniques for Attaining Efficiency are not Specified.
DEA cannot specify the techniques required for a DMU to become efficient. Only the location and magnitude of efficiency is identified. DEA locates relative inefficiencies and gives information on the input and output levels required for a DMU to be efficient, it does not identify any particular route or techniques to be followed to attain that efficiency. Hence effective use of DEA is still dependent on the judgement of management.

3. Absolute Efficiency is not Measured.
Being a technique that identifies relative and not absolute efficiency, DEA does not necessarily highlight all inefficiencies that exist. Inefficiency consistently occurring throughout the DMU set would not be highlighted. This is not a problem exclusive to DEA however as no techniques exist which can measure absolute efficiency.

4. Weight Variability.
Variable weights in DEA are set in such a way as to show each DMU in the best way possible. The only restrictions being that the same weights must not produce an efficiency score of greater than one in any other DMU, and that all weights should be positive. This means that the weights assigned to each variable may vary considerably in an ordinary DEA model. In an application to higher education, a DEA model used by Beasley (1993) assigned weights which implied that one research postgraduate was worth 888000 undergraduates (p11), an obviously incredible specification. This sort of range in weights assigned can occur because DEA is free to assign weights which can virtually ignore the least favourable variables for a particular DMU. The requirement that weights should not be able to take zero values is not sufficient to ensure that all variables have a significant impact on the results for each DMU as some variables may be assigned such small weights so as to be virtually negligible. DEA thus allows a great deal of

freedom in setting weights and assessing the relative importance of different variables. This may be seen as a crucial weakness to managers using the technique as variables which they consider as vitally important may be virtually ignored. There is scope for restricting the weights DEA assigns but this is a complex process and suitable software is unavailable at present.

5. Sensitivity to Data Error.

DEA can be quite sensitive to data error, especially where the error affects the specification of the frontier. The reason for the sensitivity of DEA is that with this technique, everything is evaluated relative to a frontier and so any single DMUs on that frontier can have a significant effect on the assessment of many or all of the inefficient DMUs. Should a DMU be incorrectly recorded as efficient due to data error, it could potentially invalidate the results of any other DMU not on the frontier. With regression, an error in data would affect the position of the regression line but, as it is an averaging technique, the effect would be dissipated. Thus a single error either in the inputting or collection of data for a DEA run may jeopardise the integrity of all of the results obtained.

6. Unenveloped DMUs.

Some DMUs may be identified as efficient because of their particular variable mix but without enveloping any other DMUs. These DMUs are known as outliers and their efficiency is not really being tested by the DEA. For example, figure 3.8 is a plot of the data from table 3.1 but with DMU F removed. The efficient frontier is still the same. The figure shows that DMUs A and C form the reference set for DMU B and DMUs C and E form the reference set for D. DMUs G and H, although they are on the frontier, do not envelope or dominate any other DMUs. Thus, their efficiency is not being tested by DEA and they can be called outliers.

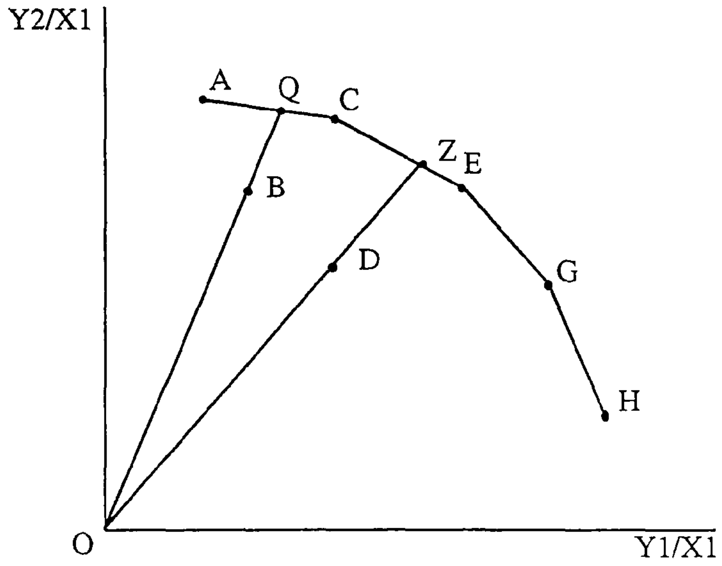

Figure 3.8 Illustration of Outliers in DEA

7. Effect of Model Misspecification.
The inclusion of an inappropriate variable or exclusion of a relevant variable are both likely to profoundly affect the results of a DEA model. A DMU may be falsely identified as efficient by focusing on the inappropriate variable. In the opposite case an efficient user or producer of a relevant but excluded variable will be unfairly discriminated against.

8. Complexity.
DEA is a very complex technique and is therefore difficult for many managers to understand. This lack of understanding may cause problems for the acceptance of DEA as a valid performance measurement tool.

9. Data Availability and Costs of Collection.
Obtaining sufficient suitable data for DEA may be very time consuming and costly, as the information required might not be readily produced by existing information systems.

10. Requirements for the Use of DEA.
There are a number of requirements which need to be met for the use of DEA. These add to the difficulties of implementing the technique.

i. Conditions for DMUs
   DMUs must be sufficiently homogeneous, facing similar market conditions, having similar objectives and with the same factors characterising performance (Golany and Roll (1989)).

ii. Conditions for Variables.
   Only quantitative data can be included (or qualitative data that can be expressed in quantitative terms). The type of data that can be used also needs to be taken into account. Per Epstein and Henderson (1989), DEA, being a ratio-based technique, implicitly assumes that

only ratio scaled data is used (although some extensions have allowed for categorical data).

The number of variables used is subject to some constraint. The maximum number of variables that can be included is dependent on the number of units in the analysis. The reason for the restriction is that the greater the number of variables in the model, the greater the opportunity for each DMU to find its own "niche" of efficiency and hence the discriminatory power of the model is reduced. This restriction must, however, be considered in conjunction with the requirement that all relevant factors should be included in the analysis, failure to do so biasing the model against efficient use of that particular factor (Sexton (1986)). The lack of any real guide-lines on the ratio of variables to DMUs adds to the difficulty of formulating models. The number of variables included can be increased, nevertheless, without losing discriminatory power, through the use of "window analysis" (Charnes et al (1985)) where DMUs are included with data pertaining to several different time periods simultaneously, thus expanding the DMU set.

A final requirement for variables in DEA is that inputs should be output augmenting. Where the opposite situation exists the reciprocal of the variable concerned should be used instead.

3.5 Summary

Data Envelopment Analysis is a complex technique involving quite extensive explanation before it can be applied in any particular context. This chapter has explained the theory on which DEA is based including graphical and mathematical representations of the technique. A section was included which explained the results produced by DEA. This involved the inclusion of templates and sample calculations and the use of sample calculations with variable weights and reference sets. This was followed by a section detailing the strengths and weaknesses of DEA as a performance measure.

In the following chapter, the methodology is presented for the application of DEA and various other techniques for the measurement of performance in higher education.

METHODOLOGICAL APPROACH

4.1 Introduction

The intention of this chapter is to explain how the technique of Data Envelopment Analysis is to be applied and evaluated in the context of the academic departments of the University of Glamorgan, and to give appropriate reasoning for the approach adopted.

The application of DEA is a quite complex process involving the stages of selection of DMUs and variables and presenting the data contained in those variables in an appropriate manner. The formulation of the DEA model is then considered and then, once the results of the DEA run are obtained, it is necessary to test their robustness and sensitivity to error.

The next stage is to compare the DEA results with those produced by other evaluation techniques. The processes for obtaining results from each of the evaluation methods are considered individually. The final section involves consideration of the comparison process, which will enable conclusions on the hypothesis to be drawn.

4.2 DEA Methodology

The process of applying Data Envelopment Analysis is split into several stages as per Golany and Roll (1989). Firstly the selection of Decision Making Units (DMUs), followed by the selection of variables, the appropriate treatment of those variables and then the analysis of data via a suitable DEA model. The analysis of results is dealt with in a subsequent section.

4.2.1 Selection of DMUs

DMUs are a set of comparable or homogenous units. Golany and Roll (1989,p239) defined homogenous units as a group where:-

" - The units under consideration perform the same tasks, with similar objectives.
- All the units perform under the same set of market conditions.
- The factors (both inputs and outputs) characterizing the performance of all units in the group are identical, except for differences in intensity or magnitude."

Academic departments in the University of Glamorgan perform the same tasks and work under a common mission statement so their objectives are very similar. The market conditions are similar as all undergraduates apply through a common system and departments share the same central facilities and geographical location. The factors, used in the DEA models, by which performance is to be measured, are those which are common to all departments.

The selection of DMUs involves the determination of the size of the group which is to be analysed. As mentioned in the theory chapter, the larger the group, the more variables that can be included in the analysis. As the number of DMUs increases though, the lower the homogeneity tends to become.

Other considerations for the selection of DMUs are physical and organisational boundaries, and the time periods over which the DMUs are to be examined. Golany and Roll suggested that time periods should be "natural", i.e. corresponding to seasonal cycles. A further question is how far back the analysis should stretch and whether it should involve "window analysis". This is where units are included in the analysis separately for different time periods.

In the University of Glamorgan (at the time of the study), there are twelve academic departments organised into three faculties. The departments are the lowest level of organisation suitable to be classed as DMUs as any further breakdown would result in units not being sufficiently discrete to be analysed individually. The University structure is, thus, the organisational boundary in DMU selection. The natural time period is an academic year and window analysis is necessary in order to allow a greater range of variables to be used. The limit on the window analysis is two academic years as prior to 1989/90 the departments were organised differently and the latest year for which data is available at the time of this study is 1990/91.

4.2.2 Selection of Variables

In an application of DEA to teaching hospitals, Sherman (1988) began the variable selection process by listing all identifiable inputs and outputs. This suggests that the initial list of potential variables should be as wide as possible and include all factors that have a bearing on a DMUs performance, whether quantitative or qualitative, discretionary or non-discretionary.

In the University, this list was generated by a number of department heads interviewed individually. Thanassoulis et al (1987, p394) noted that the variable selection stage "would normally involve wide consultation with those being assessed". The procedure adopted is in accordance with this. Eight department heads were interviewed including representatives from all faculties and they were asked which inputs and outputs they see as most important for an academic department. The list generated was quite extensive and is shown in Fig 4.1

Outputs		Times Quoted
Graduate Output	Graduate Employability	4
	Retention Rates	2
	Value Added	2
	Graduate Quality	1
Research Output	Conference Attendance	2
	No. Research Students	1
	No. Higher Degrees	1
	No. Refereed Papers	1
Income Generation		6
Recruitment Ability		5
No. Students		3
No. Courses		2
Staff & Student Satisfaction		2
Staff Motivation		2
Preparation Time		1
Adherence to Mission		1
Short Course Provision		1
Consultancy Income		1
Staff Interaction		1
Laboratory Provision		1
Room Occupancy Rates		1
Environmental Awareness		1

Inputs	Times Quoted
Finance	3
Staff	3
Student Entry Levels	2
% of Non-Standard Student Entry	2
Room Space	1
External Consultancy	1
Esteem in which Department Held	1
Average Student Contact Hours	1
Market Difficulty	1

Figure 4.1 Suggested Variables

In the judgemental screening stage of variable selection, there are a number of questions to be considered. The most pertinent here is whether data are readily available and generally reliable. When applying that constraint for the University of Glamorgan, the list of variables is reduced considerably. The revised list is shown in figure 4.2.

	<u>Outputs</u>
	Graduate Output
*	Retention Rates
*	Value Added
	Research
*	No. Higher Degrees
*	No. Refereed Papers
*	Conference Attendance
*	Income Generation
	No. Courses
*	No. Students
	Laboratory Provision
	<u>Inputs</u>
*	Finance
*	Staff
*	Room Space
	Average Student Contact Hours
*	Student Entry Levels
	% of Non-Standard Student Entry

Figure 4.2 Suggested Variables - with available data

Although many variables are possible, DEA requires a limited number. If the variable set is not limited, there would be too many degrees of freedom, and consequently the model would have minimal discriminatory power. The variables marked with an asterisk are those to be considered further. Laboratory provision and Course numbers are not included. Laboratories are not used by all departments, thus this variable would not conform to the strict-positivity requirements of DEA variables. A measure of the number of courses may provide an indication of diversity but would imply that a larger number of small courses is more desirable and it is felt that this assumption may distort the comparison.

There are two input variables omitted from the list for further consideration also. Gadenne and Cameron (1991) saw the value of contact hours as an input to be questionable. The number of student contact hours is not a true input but is just one element of the teaching process. The true input is the staff input which is already being considered. The % of Non-Standard entry is covered in the Student Entry level input.

The reduced list contains eight output and four input variables. This is still too many for a DEA containing only 24 DMUs as it would mean too many degrees of freedom, thus causing the model to lose discriminatory power. However, it is possible to aggregate elements of all these factors into a smaller number of variables.

4.2.2.1 Input Variables

Total Expenditure

One key input is the number of staff in each department. However, there are various grades of staff and the question arises of how these should be combined. Golany and Roll advocate that an important consideration is whether factors which can be measured in economic terms should be aggregated. Thanassoulis et al (1987), in an application of DEA to rates departments made a decision to use total costs as an input variable on the grounds that these costs represent the real resources used and available for management deployment. Staffing is one of these factors and so may be included as a financial measure as part of the total expenditure incurred by each department. The expenditure section in the annual accounts shows staff costs separately by department, so data is easily available.

Another relevant area of expenditure, although not included in the departmental accounts, is the expenditure on learning resources used by each department's students. The two major areas of expenditure are the Library and the Information Technology Centre (ITC) but as they are centrally funded it is difficult to allocate the expenditure to departments. The basis used for allocating ITC expenditure is by a series of random samples of centre users. The service the centre provides is a networked mainframe computer system accessible throughout the university. It is possible at any one time to identify how many staff and students are accessing the system, so ten samples were taken spread randomly over the centre's operating hours for one week. ITC expenditure was then allocated accordingly. Library expenditure was allocated on the basis of the number of book issues made to students and staff in each department. Hence the total expenditure variable is created including staff costs, both academic and administrative, departmental non-staff running costs and proportional library and ITC expenditure.

Room Space

The rooms variable is included as a separate input. Although it may be possible to allocate a per metre squared charge for room use and thus aggregate the variable with total expenditure, this is felt to be unwise because space at the University of Glamorgan is one of the key constraints. The use of that specific resource by departments is, therefore, of considerable interest to managers. The room space measure consists of a metre squared total for all types of room allocated to each department. These room types are teaching, staff, laboratory and storage rooms.

4.2.2.2 Output Variables

Value Added

This is a composite measure which can incorporate graduate results, retention/wastage rates and also the input variable of student entry levels. A number of studies have been carried out on the subject of value added. The PCFC/CNAA (1990) produced a quite comprehensive report entitled "The Measurement of Value Added in Higher Education" which identified a number of methods of measuring value added. It concentrated on measuring these on a nationwide basis but the principles are applicable to institutional or departmental measurement. The two method types are index and comparative value added (CVA). The most suitable type for this study is the comparative method as it is less subjective and does not involve the arbitrary judgement of the difference between entry and exit levels as does the index method. CVA involves comparing actual exit scores with expected scores, given a range of entry scores. The following data is required.

1. Entry Scores
2. Exit Scores
3. Completion data (Retention/Wastage rates)

1.Entry Scores

The data produced by the University system includes A level points scores for each student. The data applies to those students graduating in 1990/91. In a number of cases the students enter with qualifications other then A level. Although this is a relatively small proportion of students and quite evenly spread across departments, it was felt to be necessary to find some indicator for non A level entrants. To this effect, admissions tutors for all courses were interviewed. The information requested was the minimum A level points that would be required for entry into each course. All non A level students were then assigned this entry level as a proxy. The use of proxies where data is unavailable was suggested by Thanassoulis et al (1987). Thus all students graduating in 1990/91 have an entry level assigned to them.

2. Exit Scores

These are more complex than entry scores. This is because students may have attended for between 1 and 5 years full time on single courses or up to six years part-time. These differences need to be taken into account.

The exit scores are constructed from the two components of grade points and credit points. The University operates a system called the Credit Accumulation and Transfer Scheme (CATS) whereby all courses are credit rated. The award of an honours degree requires the accumulation of 360 credit points whilst HNDs vary according to discipline at around 200-240 points. Grade points are awarded on a a scale of 0-20 and correspond to specified percentage bands on the scale shown in figure 4.3.

Percentage	Grade Points	Honours Class
85+	17	
80-84	16	1st Class/Distinction
75-79	15	
70-74	14	
67-69	13	
64-66	12	II i/Credit
60-63	11	
57-59	10	
54-56	9	II ii
50-53	8	
47-49	7	
44-46	6	3rd Class
40-43	5	
39	4	
37-38	3	
35-36	2	
Below 35	1	

Figure 4.3 Grade Points Scale

For the value added calculation each student's exit score was calculated by multiplying the grade points awarded by the credit rating of the particular course followed. Where classifications were used such as first class or upper second, the grade points assigned were those corresponding to the centre of the classification band (an upper second class degree would receive 12 grade points, for example). Courses without classifications were assigned nine grade points unless they were awarded with distinction where fifteen grade points were given (the same points as for a first class degree).

3. Completion Data

It is important to know, in addition to those students being awarded qualifications, what proportion of students have completed courses. The data used to measure this is the number of enrolments less withdrawals and discontinued students. Referrals are not included as non completion. Separate data were used for full and part time students. As data for value added involves information on a large number of students, a sample of forty students per course was used. Where the course contained forty or less students, data for the entire cohort were included. This approach resulted in data from 1471 students being used out of a total of 1804 students graduating in that year.

Value Added Calculation

The value added calculation used was devised specifically for this study because even the comparative value added methods developed by the CNAA (PCFC/CNAA 1990) include arbitrary weightings on degree classes which were felt to be unacceptable as they are not truly empirical (Gallagher, 1991, p.27). The data used by the CNAA was also drawn from a national database with figures relating specifically to degree courses. As not all courses in the University of Glamorgan are degree level, it is not appropriate to use such a restricted database in calculating a value added measure. Hence, the value added score explained in this section is based entirely on data gathered within the institution and not any external databases. This score measures the actual performance of each department's students relative to their expected performance, given their entry scores. The expected exit scores are based on the average performance of students. The per student exit scores for each department are measured as a proportion of average entry scores. This proportion is the factor by which the average exit scores are multiplied in order to produce an expected exit score. The expected score is then compared to the actual result achieved to give a value added score. An example is given in figure 4.4.

Department X Average Entry Score		8
University Average		10
Dept X as proportion of average		80%
University Average Exit Score		100
Expected Exit Score	80% * 100	80
Actual Exit Score		90
Value Added per Student	90/80	1.125

Figure 4.4 Example Value Added Calculation

A score of 1 would indicate performance is exactly as expected and greater than one is a better than expected score. The actual calculations are far more complex than the illustration in figure 4.4 as they take into account different results for full-time and part-time attendance modes with different proportions of students in each mode of attendance for different departments. The calculations also take into account the number of students not completing courses, i.e. wastage. The actual calculations with appropriate notation and a sample calculation are shown in Appendix B on page 194.

The value added score is thus based on relative performance of students in each department and not on any subjective assessment of differences between entry and exit qualifications. A department achieving exactly the results expected would therefore be assigned a value added score of 1. This value added per student is multiplied by the number of Full Time Equivalent Students (FTES) in each department to give a total departmental value added score.

Student Numbers

The number of Full Time Equivalent Students (FTES) was considered for use as a variable either untreated or multiplied by WAB weightings to counterbalance the extra resources required for certain disciplines. This was rejected because FTES is already used in the analysis as a part of the value added variable.

The value added needs to be multiplied by FTES because, theoretically, a department could spend all resources on one student and produce an extremely high per student value added score whilst another department may be deemed less efficient by a slightly lower score but with any number of additional students at this level. Hence, the total value added score per department is required and not a per student figure.

Research

A number of methods are possible for the measurement of research, such as citations, publications or research grants. There are many difficulties associated with this measurement. Hare and Wyatt (1988,p322) commented that "in the absence of market-based output measures in the research sector, it is tempting to resort to other simple measures like the number of publications.". Even where measurement of publications is used, the problem arises of what should be included (Johnes 1988) and how publications should be quantified.

In order to give a general measure of the level of research (or scholarly activity) in each department, a quite broad measure is used in the University of Glamorgan study. This measure is a simple aggregation of the total number of publications and conference papers presented by staff plus the total number of higher degree awarded in each department. An aggregation of these measures was proposed by one member of senior management of the university at the initial stages of variable selection.

In a study of publishing performance in economics, Bell and Seater (1978) used an article count. Articles were attributed to departments in which the author was currently located. An acknowledged criticism of this was that a highly rated department may be staffed by academics who were once highly productive but are no longer so. This study of the University of Glamorgan overcomes this criticism to an extent because the data used relates to articles published in a three year period so older articles would not be included. Where articles are written by more than one author and they are not all affiliated to the same department, an appropriate proportion of the article is attributed to each department. The source of data is the institutional biannual Research and Consultancy Report in which all publications, conference papers and higher degrees are recorded. The information is presented in calendar year order. The years included are 1989, 1990 and 1991. To give a measure that corresponds to academic years, the totals were adjusted whereby the 1989/90 total includes two-thirds of the 1990 total and one-third of the 1989 figure. The 1990/1 figure was calculated similarly. No differentiation between articles was made. This is because the data is insufficiently detailed and, in any case, according to Johnes (1988), any rules for weighting articles would inevitably be arbitrary.

Thus the scholarly activity variable gives a broad indication of the level of activity in each department and not a measure of the quality of output.

Income Generated

This variable refers to the amount of income each department is responsible for generating. Income is split into different categories of fees and Welsh Advisory Board (WAB) funding. The fees are further split into home and overseas students fees. There is also some miscellaneous income but this is a very small proportion of total income. The fees and miscellaneous income are very simple to allocate as they are separated by department in the accounts for the institution. The allocation of WAB income is more complicated however. WAB allocates income to programme areas based on the number of students in each area. This is based on home (i.e. UK) students only and not the total student numbers. Each programme area has a weighting to account for the higher costs associated with certain disciplines. These costs are those such as laboratory and equipment provision. The programme areas correspond to different departments and the weightings assigned by WAB are shown in table 4.5.

Department	Weighting
Business and Administration	1.23
Humanities	1.0
Law and Finance	1.23
Management Studies	1.23
Computer Studies	1.69
Electronics and Information Technology	1.69
Maths and Computing	1.69
Mechanical and Manufacturing Engineering	1.77
Behavioural and Communication Studies	1.31
Civil Engineering and Building	1.77
Property and Development Studies	1.61
Science and Chemical Engineering	1.61

Table 4.1 Departmental Welsh Advisory Board Weightings

Although the amount of WAB funding is decided by programme area, it is not split as such when paid to the institution but is received in the form of a block payment. In order to allocate appropriate proportions of this block payment to each department the procedure adopted is as follows. The total home fees for each department are weighted by the corresponding programme weighting. The WAB funding is then allocated in direct proportion to the weighted total of home fees for each department. If total home and overseas fees were used, there would be an element of double counting because overseas fees are much higher than home fees with the difference accounting for the absence of central funding for overseas students. The reason for using fees instead of student numbers is because departmental student number figures do not differentiate between home and overseas students. Fees charged for home students in each department are constant however, so allocating via home fees will not distort the comparison.

4.2.2.3 Variable Summary

The variables to be included in the DEA are therefore:-

Inputs	Outputs
Total Expenditure Room Space	Income Generated Scholarly Activity Value Added

Table 4.2 Variables Included in DEA

Although there are only five variables they incorporate all eleven of the factors marked with an asterisk in figure 4.2. The relatively small number of variables give DEA more discriminatory power and will produce a greater range of efficiency scores.

4.2.3 Window Analysis

Window analysis is used in this study with each department appearing in the analysis twice, once for each of the years 1989/90 and 1990/91. There are some data difficulties associated with this. The total expenditure, income generated and scholarly activity variables are all constructed from data relating to relevant years. The room space variable uses the same allocations for both years (using 1990/91 data). This is not a significant problem, though, as departmental allocations change very little from year to year providing there are no institutional structure changes.

The value added variable exit and entry data is based on students graduating in 1990/91 only as 1989/90 data was unavailable. However, the 1989/90 and 1990/91 figures for enrolments, completions and student numbers are taken into account separately.

Another consideration when using window analysis is the scaling of economic factors to account for inflation. All 1989/90 prices (Total expenditure and income generation) are scaled by a factor calculated according to the change of the Retail Price Index (RPI) between academic years 1989/90 and 1990/91.

The next stage after variables are chosen and appropriately treated is the model formulation and analysis.

4.2.4 Formulation of Model

As mentioned in Chapter Three, there are a number of formulations of DEA which can be used. The two most important decisions are whether to use constant or variable returns to scale and whether the model should be input or output orientated. According to Golany and Roll (1989), the choice between input and output orientation should be made according to prevailing circumstances. In the University of Glamorgan, the rooms input is non-discretionary and total expenditure is to a large extent dictated to departments in the form of a budget. This implies that a model focusing on outputs is the most suitable as these are more capable of being under departmental management control.

The choice between constant and variable returns to scale can be made using a test of correlation between efficiency and scale. If there is a high correlation this suggests that scale is a relevant factor in determining efficiency and thus the variable returns to scale (VRS) model may be more suitable. A second test is to plot the relationship between CRS efficiency and scale (student numbers) on a scattergraph. This will show more clearly a situation where there is a non-linear relationship between scale and efficiency. For example, where there are first increasing, then decreasing returns to scale. If this is the case then the VRS model may be more suitable. However, the constant returns to scale (CRS) model has the greater discriminatory power of the two and differences in scale alone may be identified later. Hence the model on which the initial analysis is based is the output-orientated CRS model, although results of all other combinations of the two are considered as consideration of both CRS and VRS results can give an indication of what inefficiencies are due to scale. This is useful for senior management's interpretation of the results.

4.2.5 Analysis of Results

The initial analysis of the results of the constant returns to scale, output orientated model will involve looking at the number of efficient departments and the range of efficiency scores reported. This is followed by a more detailed analysis of the results of specific DMUs. The DMUs chosen for this detailed inspection are the least efficient DMU and the DMU that forms the largest element in its reference set (i.e one of the most efficient DMUs. Thus DMUs at both extremes of the efficiency rankings would be considered.)

The detailed analysis includes examination of all information produced by the DEA. An example of this information is shown on the sample template in figure 4.5. The analysis will involve consideration of the data supporting the DEA evaluation in relation to both enveloping departments and to the university as a whole. This should provide reasons for the reported results and highlight any relative strengths and weaknesses shown for that particular department.

Department: A

Model: Output oriented CRS Efficiency Score: 0.85

Outputs	Observed	Projected	Slack	Weight
Y1	85	100	0	15.35
Y2	1700	2250	250	1.00

Inputs	Observed	Projected	Excess	Weight
X1	38	26	12	1.00
X2	2000	2000	0	114.65

Reference Departments

Department	Weight
B	0.63
C	0.21
D	0.48

Figure 4.5 Departmental DEA Results Template

Consideration of the data underlying both enveloping and inefficient departments in the evaluation should confirm the results given by DEA. However, there is the possibility of data error or incorrect specification and the effect of these on the DEA evaluation are considered in the following section.

4.2.6 Sensitivity Analysis

Smith and Mayston (1987,p186) stated that "In order to throw what light one can on the reliability and robustness of the position of the efficiency frontier under DEA, and implied deviations from it, it therefore becomes desirable to carry out an analysis of the sensitivity of the results of DEA to a number of underlying factors". One of the factors identified was the position of "extreme" DMUs, that is those DMUs that are on the efficient frontier and form part of the reference set for many inefficient DMUs. This means that any data error or mis-specification in an extreme DMU could affect the results for a large part of the analysis.

The method for checking this sensitivity requires differentiation between efficient DMUs. This distinction is in itself a separate check on the reliability of the DEA results. Smith and Mayston (1987,p187) state that "if an authority [DMU] is initially identified as `efficient' under DEA, an important supplementary measure in assessing the robustness of this result is the number of inefficient authorities for which the authority forms the efficient frontier". This is the basis for distinguishing between efficient departments. If the number of DMUs for which an `efficient' DMU forms the efficient frontier is low or none then Smith and Mayston see a possibility of the DMU in question being efficient but that there is insufficient comparable evidence for a final judgement. This situation may occur where a DMU concentrates on one particular output at the expense of others. However if a DMU does form part of the efficient frontier for many other departments, then that constitutes sufficient evidence to ratify the efficiency score. Hence an important part of the analysis of the reliability of the DEA results is the examination of reference set tallies.

Once the method of differentiating between efficient DMUs is established and the most efficient DMUs identified, it is possible to check the sensitivity of the results to the mis-specification of extreme departmental performance. The method used is to remove the single most quoted DMU from the data set and to re-run the analysis without it. The results are then compared to the results produced with the full DMU set. A large increase in efficiency in some units would indicate a significant sensitivity to mis-specification and could thus undermine the integrity of the DEA results. However, if the results do not change significantly, this would attest to the robustness of the model to faulty data in that DMU.

Removing one DMU alone, however, may not be a sufficient sensitivity check. Hence the procedure is to be repeated twice with the most efficient department in the reduced set being removed each time and the consequences analysed.

A further analysis of the robustness of efficiency proposed by Smith and Mayston is a check of the extent to which the omission of one input or output variable would make a DMU inefficient. For the University of Glamorgan study, it is proposed to extend this to removing each variable in turn and considering the effects of their systematic removal on each DMU. The effects on efficiency scores, projected values, slack values and the reference set will be considered. Any profound deterioration could indicate an over-reliance on the particular variable being removed and may require further investigation of the performance of the DMU in question.

Aside from the identification of outliers and extreme DMUs, the combination of the sensitivity analyses may also enable some conclusions to be drawn on the limitations of the DEA formulation used (and DEA in general). A substantial sensitivity to the checks used could undermine the viability of the application of the technique in this context whilst a display of robustness would support its use. Hence the sensitivity analysis of the DEA results is a fundamental aspect of the methodology of this project.

4.3 Regression Methodology

In applying regression to the University of Glamorgan, the same data set is used as for DEA but, in order to try and find appropriate input output relationships, the disaggregation of some variables and the weighting of some by WAB weightings is required. The variable list is thus as follows:-

Value Added
Income Generated
Research
Total Expenditure
Room Use
Weighted Total Expenditure
Direct Expenditure
Resource Use

Weighted Total Expenditure is the total expenditure variable per DEA but weighted by the reciprocal of the WAB programme weightings. This is intended to account for the different cost levels inherent in each discipline. Direct Expenditure is total expenditure less the allocations for library and IT Centre use. Resource Use is the library and ITC allocations. The reason for disaggregating and adjusting input variables is that only one output variable or dependent variable can be used in each regression model whilst there may be many input variables used. The DEA model contains only two inputs and so it is desirable to create more to give regression more scope.

It is necessary to account for scale in each variable used. This is achieved by dividing all variables by FTES to produce a per student figure for each. If this is not done, a correlation between variables may be reported that is due to scale and not a true relationship.

Different regression models are possible, both bivariate and multivariate. The main restriction is that only one output or dependent variable can be used in each model. In the multivariate model there is also a choice of a full model or stepwise regression. A full model regression, as the name suggests, includes all variables entered in the analysis. A stepwise model only includes those variables which meet pre-set significance criteria and contribute to the explanatory power of the model. In this case the stepwise model is to be used with criteria that the relationship should be significant at the 95% level. The models to be run are both bivariate and stepwise multivariate models with a set of regressions for each dependent variable.

Once the regressions have been completed it is necessary to identify which relationships are the most useful for measuring efficiency in the departments. A rule of thumb for the regressions is that a coefficient of (multiple) determination of around 0.50 is required with a significance level of at least 95%. This means that the probability of the results occurring through chance should be 0.05 or less.

When using regression there are a set of assumptions involved. Once it has been established that a particular model has met the assumptions, then the results need to be considered. This involves the interpretation of residuals. The residual is the distance of a particular department either above or below the regression line. The assumptions of regression are (per Mason and Lind (1990)):-

1. The independent variables and the dependent variable have a linear or straight line relationship.

2. The dependent variable is interval or ratio-scale. Interval data is data which represents relationships of rank-order with equal differences in the scale representing equal physical differences in whatever the scale measures. Ratio-scale data is similar but also has a true zero-point as its origin.

3. The independent variables are not correlated.
   Where independent variables are highly correlated with each other it is known as multicollinearity. This can be checked with a correlation matrix of the independent variables. It is possible that multicollinearity may exist without there being a single high correlation with any one other independent variable. A check for this is the tolerance of each independent variable. This shows the proportion of variation in an independent variable that cannot be explained by variations in all other independent variables. As the number of variables in this model is small, a check of the correlation matrix should suffice for a multicollinearity check.

4. Successive observations of the dependent variable are not correlated. This is known as autocorrelation.

5. Differences between actual values and the estimated values are approximately normally distributed, and they are the same for all estimated values.

This last assumption is checked by plotting residuals. The assumption that the variance of the residuals remains constant for all estimated values is the condition known as homoscedasticity. This is checked by plotting the residuals against estimated values of the dependent variable and checking the shape of the plot. If the homoscedasticity requirement is met the plot should be evenly spread.

Once it has been established that the model is sound, the results can be analysed in more detail. In the interpretation of residuals, a positive residual is a better than predicted performance given the level of the independent variables observed for a particular department. A negative residual is a worse than expected performance.

Unlike DEA, which is a frontier method of measurement, regression is a parametric technique. A decision rule may be necessary for the interpretation of efficiency through regression. It may be decided that a result of one standard deviation or more above the regression line constitutes an efficient performance or that merely any positive residual is efficient. For the University of Glamorgan study, a slightly different approach has been used to avoid a subjective definition of efficiency. The approach is a graphical one and involves comparing the observed input value with that which a department would report if it were on the regression line.

In the multivariate model the method of interpretation used involves trade-offs between inputs in the form of an "efficiency zone" within which a departments results should lie in order to remain on or above the regression line. An example of the type of graph to be used is in figure 4.6. A graphical approach is only possible, however, where the multivariate models only incorporate two independent variables. Beyond that the interpretation becomes more difficult and would involve the ranking of variables in order of importance to give an idea of the relative efficiency of each department.

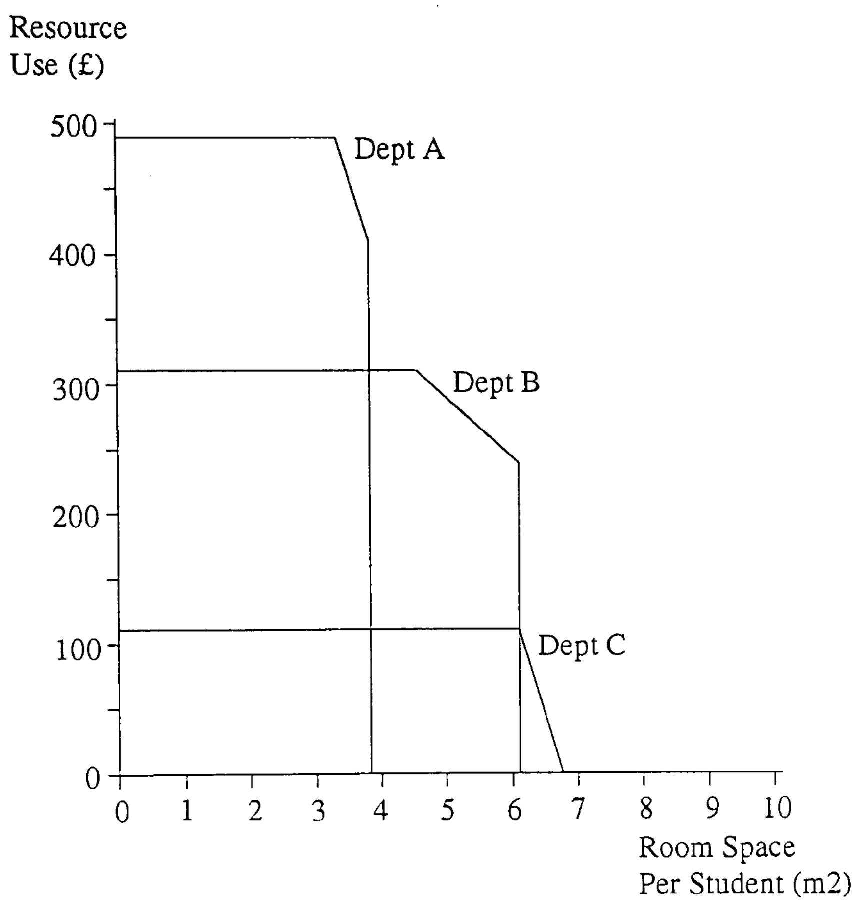

Figure 4.6 Example Efficiency Zone Graph

4.4 Financial Measures Methodology

Financial analysis is the most popular method of performance measurement in the private sector. In the public sector, although many activities are not measurable in monetary terms, financial constraints necessitate the analysis of costs and revenues incurred by public sector institutions and departments. In this study, three possible approaches are considered. These are full cost, contribution and activity based costing approaches.

The full cost approach considers the revenues received and costs incurred across the university by and on behalf of each department. This involves the allocation of the costs of central services such as the library and technology facilities and administrative services to each academic department. These allocations would be made in accordance with some appropriate factor. For example, the costs of the personnel division could be allocated in accordance with the number of staff in each department.

The full cost approach gives a detailed picture of the impact of each department in financial terms although the arbitrariness of the allocation procedure may present problems. It may not always be clear which basis is the most appropriate for allocating a particular cost.

A contribution approach looks at what each department contributes to the fixed costs of the university after covering its own variable costs. Applying a contribution approach to the academic departments would also require the allocation of centrally received income to each department as a large proportion of the income received is in the form of block funding. If only fee income were included in the contribution calculation this would penalise science and technology departments as a greater proportion of the income they are responsible for generating is received centrally. The major obstacle to the use of the contribution approach is the identification of variable costs in the university.

It is not as simple to directly relate the costs incurred to student numbers as it is with income generated. In addition, many of the variable costs that exist in the university may be incurred centrally and so a reallocation procedure would also be needed here.

Activity Based Costing (ABC) is an approach based on the assumption that activities cause costs. The initial stage of ABC involves the identification of the major activities in an organisation. In the university, the major activities are teaching and research (although these can be split further). The second stage of ABC is to identify the factors that influence the cost of a particular activity, i.e. the cost drivers. The third stage is the creation of a cost centre for each major activity. The costs of each activity are then traced to products in accordance with each product's use of the various activities.

ABC is useful for costing particular products but is less helpful in costing the more generic outputs of a university because the costs incurred in the university in producing these outputs are primarily budget driven. These budgets are dependent on the income received which is in turn dependent on student recruitment. In addition there are major difficulties in determining cost drivers and this is not the primary objective of the study

Thus, the overall problems in the financial analysis of departmental performance are the absence of cost drivers and any clear relationship between the level of activity and the costs incurred. This problem precludes the effective use of either ABC or a contribution based approach. The method to be employed, therefore, is a full cost approach but with due consideration to the potential arbitrariness of the allocation bases. Adoption of this method will also allow consideration of unit cost figures based on the fully allocated cost per student incurred by each department.

The data for departmental income and expenditure is obtained via the institution's annual accounts. This data requires some adjustment for central funding and expenditure. The purpose is to allocate the entire income and expenditure of the institution to academic departments, each different type being allocated on an appropriate basis. The format of each departmental income and expenditure account after allocations were decided and completed is shown in figure 4.7 with a more detailed example in Appendix D.

	£	£
Direct Income	x	
Allocated Income	x	

Total Income		xx
Direct Expenditure	x	
Allocated Expenditure	x	
	---	
		xx

Total Income less Total Expenditure		xx
		====

Figure 4.7 Income and Expenditure Account Format

The accounts from which the information is drawn contain minimal detail for departmental level expenditure with only direct income and expenditure attributed to departments. All other income and expenditure has been apportioned to the appropriate departments. The allocation bases used for this depend on the nature of each item of income or expenditure and are described below.

Direct Income

This is income to departments in the form of fees paid by Local Education Authorities and overseas students. It also includes income from consultancy work undertaken by staff in the relevant department.

Direct Expenditure

This is expenditure incurred by each department in respect of staffing, office supplies and transport. It includes all expenditure directly met by the department.

Allocated Income

1. WAB allocation and MGCC Top-up.
This is allocated on the basis of WAB weightings and home fees as in the income generated DEA variable.

2. Debt Charges
Debt charges relates to funding for university buildings and so are allocated on the basis of metre squared of room space for each department.

3. Early Retirement Funding
This is allocated on the basis of full time equivalent lecturers.

Allocated Expenditure

1. Faculty Office expenditure, Continuing Education Department, Academic division, Administrative division, reprographics, publicity, Learning Resources, ITC, Student Services.

These are all allocated on the basis of full time equivalent students as the expenditure each department is responsible for is largely dependent on the proportion of the university's total students that are enrolled in that department. For example, the cost of work undertaken by the academic division is directly related to student numbers as it involves administration of the admission of students and the issue of individual course results and qualifications.

2. Personnel, Early Retirement, Staff Development
The most appropriate allocation basis for these is full time equivalent lecturers as expenditure in each of these categories is dependent on staff numbers.

3. Safety, Refectory, Playgroup.
These are allocated on the basis of the total FTES and FTEL as the services are used by both staff and students.

4. Buildings, Cleaning, Security
The costs of these are allocated according to floor space.

5. Finance Department, Directorate, Central Administration Recharges
These are allocated on the basis of direct costs per department.

In addition to reallocations of central income and expenditure, some reallocation of departmental finances are required. This is due to the reorganisation of departments in the Faculty of Professional Studies during Financial Year 1990. This was dealt with by analysing the movement of staff in the reorganisation and allocating income and expenditure accordingly.

Two financial measures are to be used in the comparison, the first is an income expenditure account as explained above. The second is a unit cost figure per department. This is calculated by adding the direct and allocated expenditure and dividing the total by the number of full time equivalent students. This measure does not incorporate any WAB weighting. For both of the financial measures, the 1989/90 figures are scaled by the same RPI factor as in DEA to ensure comparability across both years of the analysis.

4.5 Ratio Methods

The ratio methods involve the analysis of the ratios supplied by the Further Education Management Information System (FEMIS). These ratios are currently used by the university for efficiency measurement. The ratios produced are as follows:

Staff-Student Ratio (SSR)

Average Contact Hours (ACH)

This is the average weekly number of hours each student has contact with a member of teaching staff.

Average Class Size (ACS)

Average Lecturer Hours (ALH)

The calculation of these is quite complicated and guidance for this is given in a Department of Education and Science publication titled Annual Monitoring Survey of Further and Higher Education Student:Staff Ratios, Notes for Completion (DES 1990).

Together the ratios give a profile of each department's teaching. No adjustment of these ratios is needed. They are used in the University to give an indication of teaching throughput. The higher the SSR, the greater the throughput. Use of a single ratio gives a simple, though incomplete, method of comparing each department's teaching efficiency.

4.6 Comparison of Results

In order to be able to draw conclusions on DEA's usefulness and the information it provides, it needs to be considered in conjunction with other methods. One question to be asked is whether it provides the same level of information as other methods. This comparison can be effected by comparing results profiles from each of the methods and looking at how each method presents the performance of individual departments. Although these comparisons cannot be expressed in quantitative terms they are important as an indication of the breadth and depth of information provided by each technique.

One common feature of results of all of the methods is that they can be ranked quite simply. The degree of similarity in how each method rates the relative performance of each department can be established by comparing these rankings. The measure to be used for this is the Kendall Coefficient of Concordance which expresses the relationship between more than two sets of rankings. The formula is as follows:-

$$W = \frac{12 \Sigma (R - \text{Mean } R)^2}{K^2 (N^3 - N)}$$

Where:-

W = Kendalls Coefficient of Concordance.
R = Total of ranks for each department.
K = Number of judges (measurement methods).
N = Number of departments.

The result is a score of between 0 and 1 where 1 signifies complete agreement of all of the measurement techniques.

Kendalls Coefficient will be applied firstly to all of the methods together to check the overall agreement of the rankings. Following this, the coefficient will be calculated with each of the methods being excluded in turn. The result of this will be compared in each case with the overall concordance figure to show the extent to which the excluded ranking affects overall concordance. A large difference would signify a substantial disagreement between the method in question and the other methods overall. This method of comparison is simpler and easier to interpret than a series of bivariate correlations and will highlight any substantial differences.

4.7 Summary

This chapter detailed the procedures through which the DEA, regression, financial and ratio methods are applied to the University of Glamorgan. For DEA this is a quite extensive procedure involving calculations of complex variables such as value added. The methods for investigating the sensitivity of DEA to error and mis-specification are also detailed.

It is also necessary to make comparisons, in order that conclusions may be drawn on the relative merits and applicability of each technique (and hence the hypothesis). Methods for effecting this comparison were listed in the latter part of this chapter.

The following chapter presents an analysis of the results obtained from the application of these methods.

RESULTS

5.1 Introduction

The previous chapter presented the methodology for evaluating DEA and its use in higher education. This chapter examines the results of the application of that methodology. The results obtained are for five measurement techniques, namely, DEA, regression analysis, income and expenditure accounts, unit cost and FEMIS ratios. For DEA the results also include sensitivity analyses.

5.2 Regression Analysis

The results of the bivariate regression models are shown in table 5.1. There are two criteria involved in choosing regression models. Firstly, the size of the coefficient of determination (R^2). The models marked with an asterisk are those in which the independent variable provides explanation of a sufficient proportion of the variations in the dependent variable to be useful. The lowest R^2 of those deemed sufficient is 0.49 for Valadd as dependent variable and Direxp as independent. A second criteria for the models was that they were statistically significant. This was tested using the F ratio with a significance level of 95% or above being acceptable. This means a probability of 0.05 or less that the results were obtained by chance. Models satisfying this criteria are marked with an S.

The most informative models were those with Valadd as the dependent variable with the best being Valadd-Rooms. This relationship is not surprising due to the tendency for science and engineering departments to award a higher proportion of first class degrees (7.27% in 1990/91 compared to 1.96% for non-science departments) and the greater amount of room space used by these departments (5.97 m^2 per student compared to 2.11 m^2 for non science departments).

	DEPENDENT VARIABLE	INDEPENDENT VARIABLE	PROBAB-ILITY	R SQUARED
S *	VALADD	TOTEXP	0.00008	0.5136
S *	VALADD	ROOMS	0.00001	0.5998
S	VALADD	TEXPWB	0.01108	0.2591
	INCGEN	TOTEXP	0.12947	0.1014
S	INCGEN	ROOMS	0.00813	0.2778
	INCGEN	TEXPWB	0.8991	0.0007
	RESEARCH	TOTEXP	0.57527	0.0145
	RESEARCH	ROOMS	0.83054	0.0021
	RESEARCH	TEXPWB	0.19286	0.0758
	VALADD	RESUSE	0.58393	0.0138
S *	VALADD	DIREXP	0.00015	0.4882
	INCGEN	RESUSE	0.61952	0.0114
	INCGEN	DIREXP	0.09499	0.1215
	RESEARCH	RESUSE	0.80466	0.0028
	RESEARCH	DIREXP	0.60763	0.0122

KEY TO VARIABLES:

VALADD	VALUE ADDED
INCGEN	INCOME GENERATED
RESEARCH	RESEARCH ACTIVITY
TOTEXP	TOTAL EXPENDITURE
ROOMS	DEPARTMENTAL ROOM ALLOCATION
TEXPWB	TOTAL EXPENDITURE WEIGHTED BY WAB PROGRAMME WEIGHTINGS
DIREXP	TOTAL EXPENDITURE EXCLUSIVE OF RESOURCE USE ALLOCATIONS
RESUSE	RESOURCE USE ALLOCATIONS

ALL VARIABLES ARE PER FTES

Table 5.1 Bivariate Regression Results Summary

The residuals for each department show the vertical distance of the department's actual score from the regression line. The regression line shows average performance. A positive residual would therefore indicate a greater production of Valadd per unit of room space than average (or a lower use of rooms than average). A negative residual indicates the opposite.

There are ten DMUs with positive residuals with the most efficient being Business and Administrative Studies, Mechanical and Manufacturing Engineering and Computer Studies. These departments are all efficient in both years. The residuals as a proportion of observed values (i.e actual results) range from 29.7% to -36.7% with the worst department being Property and Development Studies in 1990/91. These results are shown in table 5.2.

Dependent Variable: VALADD

Independent Variable: ROOMS

R^2= 0.5998 Probability = 0.00001

Regression Equation: Y' = 0.713 + 0.0803X

Department	Observed Value	Predicted Value	Residual Value	Residual %	Rank
2BUSADMN	1.202	0.845	0.357	29.70	1
2HUMANIT	0.969	0.960	0.009	0.93	10
2LAWFINA	0.724	0.824	-0.100	-13.81	17
2MANAGMT	0.923	0.914	0.009	0.98	9
2COMPUTR	0.986	0.855	0.131	13.29	6
2ELECINF	1.161	1.199	-0.038	-3.27	13
2MATHCOM	1.059	0.953	0.106	10.01	8
2MECHMAN	1.829	1.500	0.329	17.99	3
2BEHCOMM	0.698	0.858	-0.160	-22.92	20
2CIVBUIL	1.103	1.381	-0.278	-25.20	22
2PROPDEV	0.722	0.987	-0.265	-36.70	24
2SCICHEM	1.305	1.332	-0.027	-2.07	11
1BUSADMN	1.232	0.867	0.365	29.63	2
1HUMANIT	0.940	0.967	-0.027	-2.87	12
1LAWFINA	0.730	0.831	-0.101	-13.84	18
1MANAGMT	0.853	0.939	-0.086	-10.08	16
1COMPUTR	1.020	0.851	0.169	16.57	4
1ELECINF	1.115	1.168	-0.053	-4.75	14
1MATHCOM	1.059	0.937	0.122	11.52	7
1MECHMAN	1.864	1.593	0.271	14.54	5
1BEHCOMM	0.718	0.863	-0.145	-20.19	19
1CIVBUIL	1.120	1.373	-0.253	-22.59	21
1PROPDEV	0.732	0.974	-0.242	-33.06	23
1SCICHEM	1.245	1.336	-0.091	-7.31	15

Table 5.2 Bivariate Regression Results Analysis

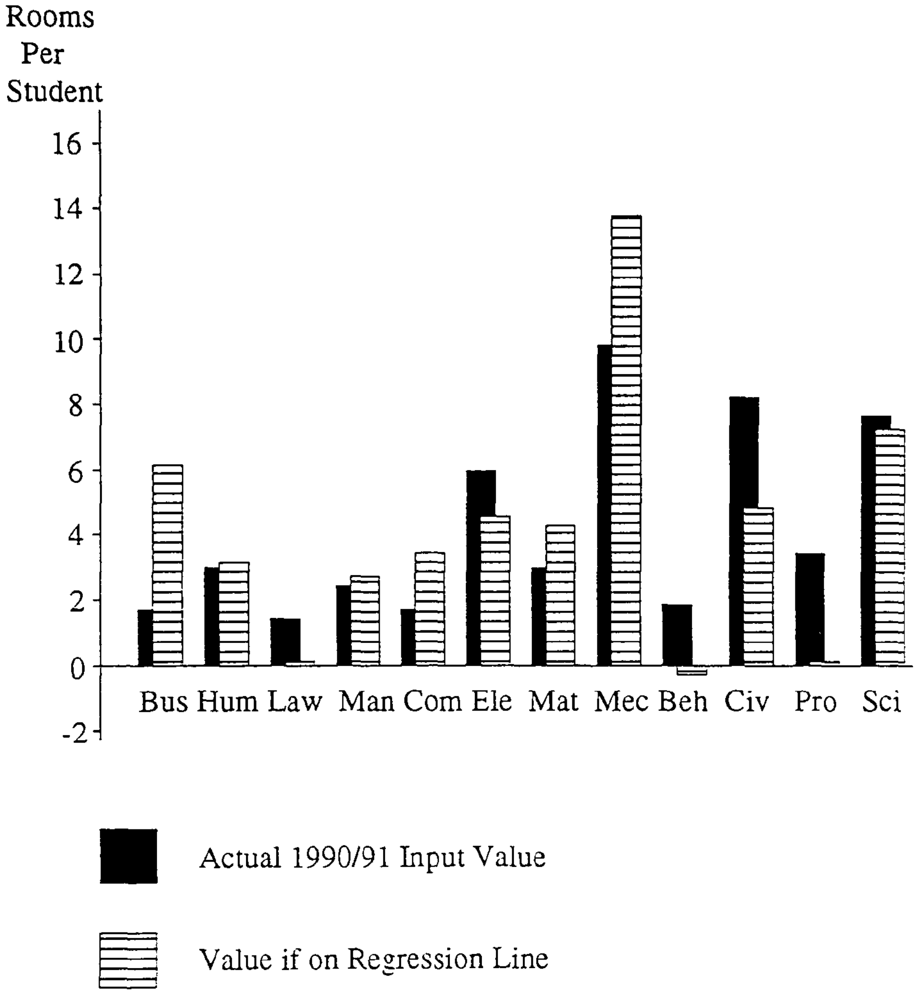

Figure 5.1 Inputs Required for Placing on Regression Line 1990/91

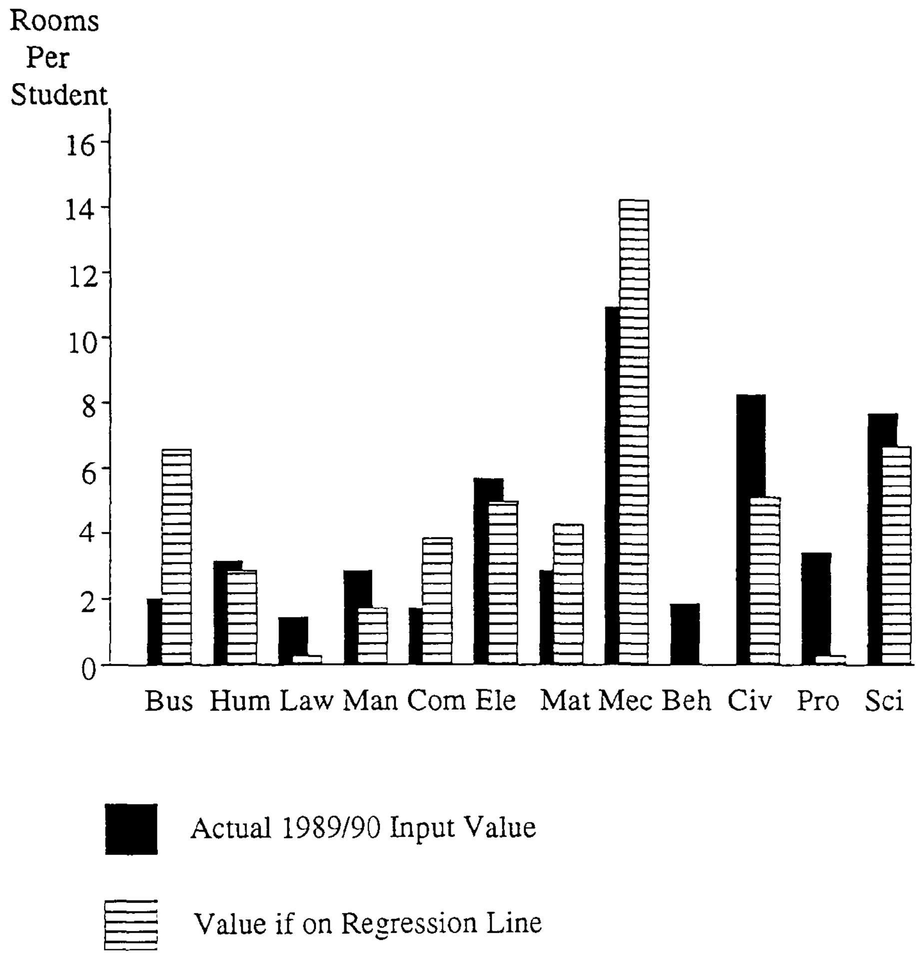

Figure 5.2 Inputs Required for Placing on Regression Line 1989/90

Figures 5.1 and 5.2 show the level of input required if a department were to be placed on the regression line through change in input alone. Figures 5.1 and 5.2 relate to years 1990/91 and 1989/90 respectively. The key to the abbreviations used for department names is contained in Appendix C. The most severe reduction shown is for Behavioural and Communication Studies in 1990/91 which actually projects a negative input of -0.18 rooms per student. This is obviously unreasonable but it does mean that the department could not become efficient with a reduction in input alone. This is true for several other departments whose projected efficient input values are so low as to be unattainable.

Where a department in figure 5.1/2 has a positive residual, this implies there is slack input for that department, i.e. it could increase its input as far as the level shown and still stay on or above the regression line. In the case of Mechanical and Manufacturing Engineering (Mechman) in both years, this level is substantially higher than any actual level of room use incurred by any department. Mechman is the largest existing room user but also has a far higher value added per student than any other department (hence the positive residual). The combination of high room use and a positive residual results in input slack leading to an extremely high potential for room use whilst still remaining on or above the regression line.

Using Valadd as the dependent variable also produced a significant result with either Totexp or the weighted expenditure variable, Texpwb as independent variables. When the expenditure variables were disaggregated into direct expenditure and resource use allocations, only the direct expenditure element proved to be useful in the bivariate regressions. Using Incgen as the dependent variable gives a statistically significant result with Rooms as the independent variable although the R squared value being only

0.28, the extent of the relationship is not sufficient to be able to apply it in measuring departmental efficiency as 72% of variations in income generated would not be explained. Using Research as a dependent variable did not produce any evidence of substantial or significant relationship between Research and any of the independent variables.

The type of multivariate regression used was a stepwise regression. This method, as the name suggests, adds or removes variables step by step to produce a model with both the highest explanatory power and statistically significant relationships. The level of significance required is an F ratio of 3 or more. Using a stepwise regression with Valadd

	DEPENDENT VARIABLE	INDEPENDENT VARIABLES	PROBAB-ILITY	ADJUSTED RSQUARED
S *	VALADD	ROOMS RESUSE	0 0.04476	0.6398
S	INCGEN	ROOMS TEXPWB	0.00208 0.09377	0.3103
	RESEARCH	NONE MEET CRITERIA	-	-

KEY TO VARIABLES:

VALADD	VALUE ADDED
INCGEN	INCOME GENERATED
RESEARCH	RESEARCH ACTIVITY
TOTEXP	TOTAL EXPENDITURE
ROOMS	DEPARTMENTAL ROOM ALLOCATION
TEXPWB	TOTAL EXPENDITURE WEIGHTED BY WAB PROGRAMME WEIGHTINGS
DIREXP	TOTAL EXPENDITURE EXCLUSIVE OF RESOURCE USE ALLOCATIONS
RESUSE	RESOURCE USE ALLOCATIONS

ALL VARIABLES ARE PER FTES

Table 5.3 Stepwise Multivariate Regression Results

as a dependent variable, Resuse was identified as a variable with additional explanatory power to Rooms. Resuse being the allocated cost to each department of its relative use of both the Learning Resources Centre and the Information Technology Centre on a per student basis. The results of the stepwise regression are as summarised in table 5.3. R^2 has increased from 0.5998 to 0.6398 (Adjusted R^2) with the addition of Resuse with the new variable being significant to the 95.5% level (1-0.045) and Rooms being very highly significant (almost 100%).

Dependent Variable: VALADD
Independent Variables: RESUSE
ROOMS
ADJUSTED R^2= 0.6398 Probability = 0.04476
Regression Equation: Y' = 0.5136 + 0.000496X1 + 0.0856X2

Department	Observed Value	Predicted Value	Residual Value	Residual %	Rank
2BUSADMN	1.202	0.815	0.387	32.20	1
2HUMANIT	0.969	0.996	-0.027	-2.79	11
2LAWFINA	0.724	0.747	-0.023	-3.18	12
2MANAGMT	0.923	0.796	0.127	13.76	5
2COMPUTR	0.986	0.945	0.041	4.16	6
2ELECINF	1.161	1.271	-0.110	-9.47	16
2MATHCOM	1.059	1.019	0.040	3.78	7
2MECHMAN	1.829	1.471	0.358	19.57	3
2BEHCOMM	0.698	0.814	-0.116	-16.62	21
2CIVBUIL	1.103	1.289	-0.186	-16.86	22
2PROPDEV	0.722	0.911	-0.189	-26.18	24
2SCICHEM	1.305	1.386	-0.081	-6.21	14
1BUSADMN	1.232	0.887	0.345	28.00	2
1HUMANIT	0.940	1.005	-0.065	-6.91	15
1LAWFINA	0.730	0.764	-0.034	-4.66	13
1MANAGMT	0.853	0.829	0.024	2.81	8
1COMPUTR	1.020	1.014	0.006	0.59	9
1ELECINF	1.115	1.273	-0.158	-14.17	18
1MATHCOM	1.059	1.067	-0.008	-0.76	10
1MECHMAN	1.864	1.593	0.271	14.54	4
1BEHCOMM	0.718	0.825	-0.107	-14.90	20
1CIVBUIL	1.120	1.279	-0.159	-14.20	19
1PROPDEV	0.732	0.894	-0.162	-22.13	23
1SCICHEM	1.245	1.417	-0.172	-13.82	17

Table 5.4 Multivariate Regression Results Analysis

The detailed results for the multivariate model are shown in table 5.4. There are nine DMUs with positive residuals with four departments positive in both years. The range of the residuals is from +32.2% of the observed value to -26.18% with the largest increase in Valadd proposed being 0.189 per student for Property and Development Studies in 1990/91. The potential reductions in inputs for DMUs with negative residuals can be identified as a trade off between reductions in each of the 2 inputs.

In the case of Electronics and Information Technology in 1990/91, a zero residual could be achieved by either reducing Resuse to a minimum level of £261.13 per student or by reducing Rooms to 4.765. The interpretation of projected input levels becomes more complicated with more than one independent variable as increases in one input are offset against decreases in another. This difficulty can be eased by presenting the results graphically in the form of an "efficient zone" for each department. Each department will remain on or above the regression line if it keeps output constant or higher and its input combination remains within its efficient zone as shown in figures 5.3 and 5.4. The corners of the zone identify the maximum permissible level of each input when the other remains constant. Eg. for Electronics and Information Technology in 1990/91 (2Elecinf), the maximum level of Resuse is £490 per student when Room use is $4.76m^2$ per student. Point A shows 2Elecinf's actual performance. The situation arises more often with multivariate regression where a projected input level is negative. This situation occurs with Civil Engineering and Building and Property and Development Studies in both years of the analysis. When showing the results graphically the efficient zone can be restricted to positive values for each input. If more than two inputs had been included in the model, however, graphical analysis would cease to be of any use for interpretation of the results.

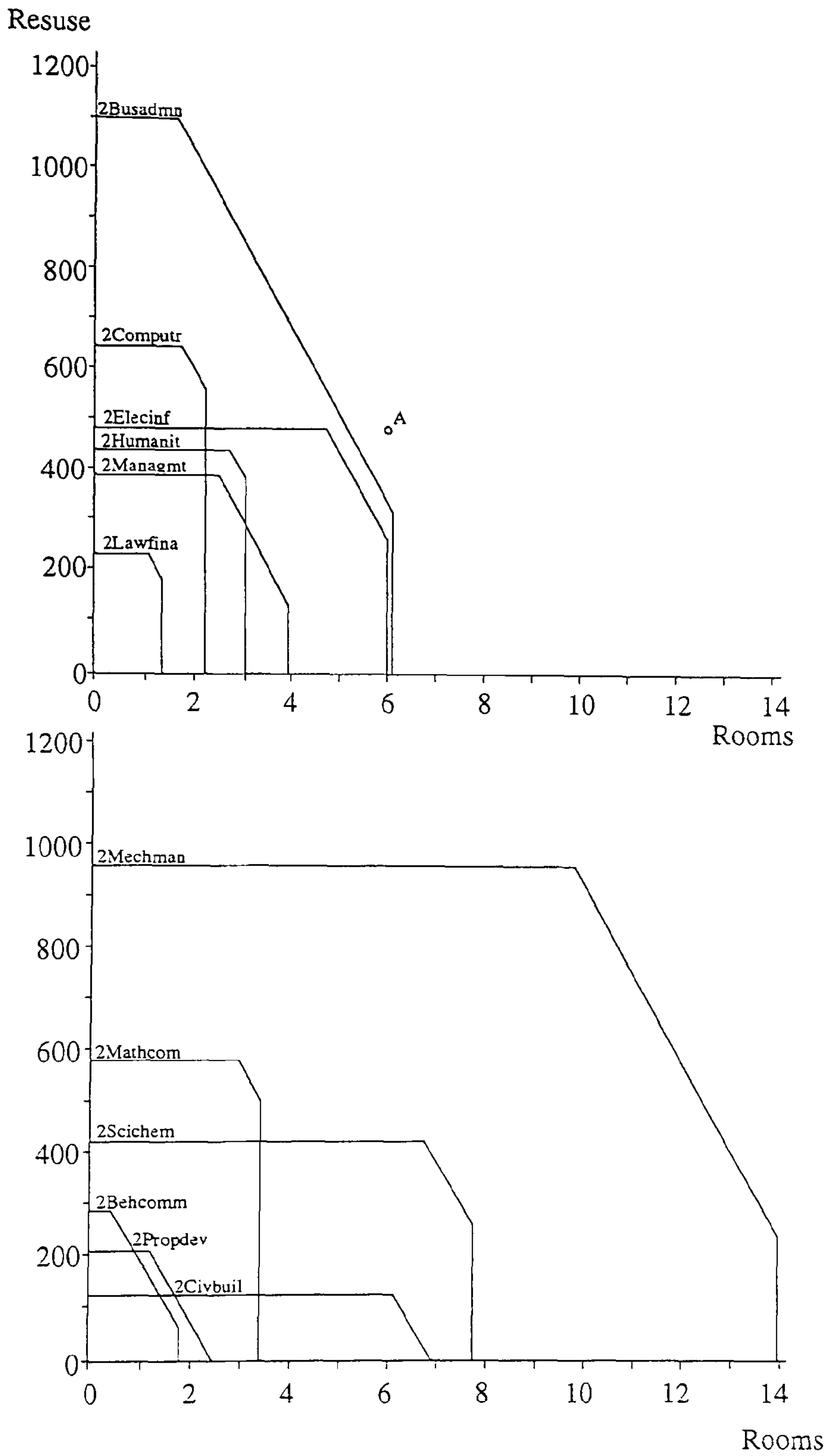

Figure 5.3 Efficiency Zones 1990/91

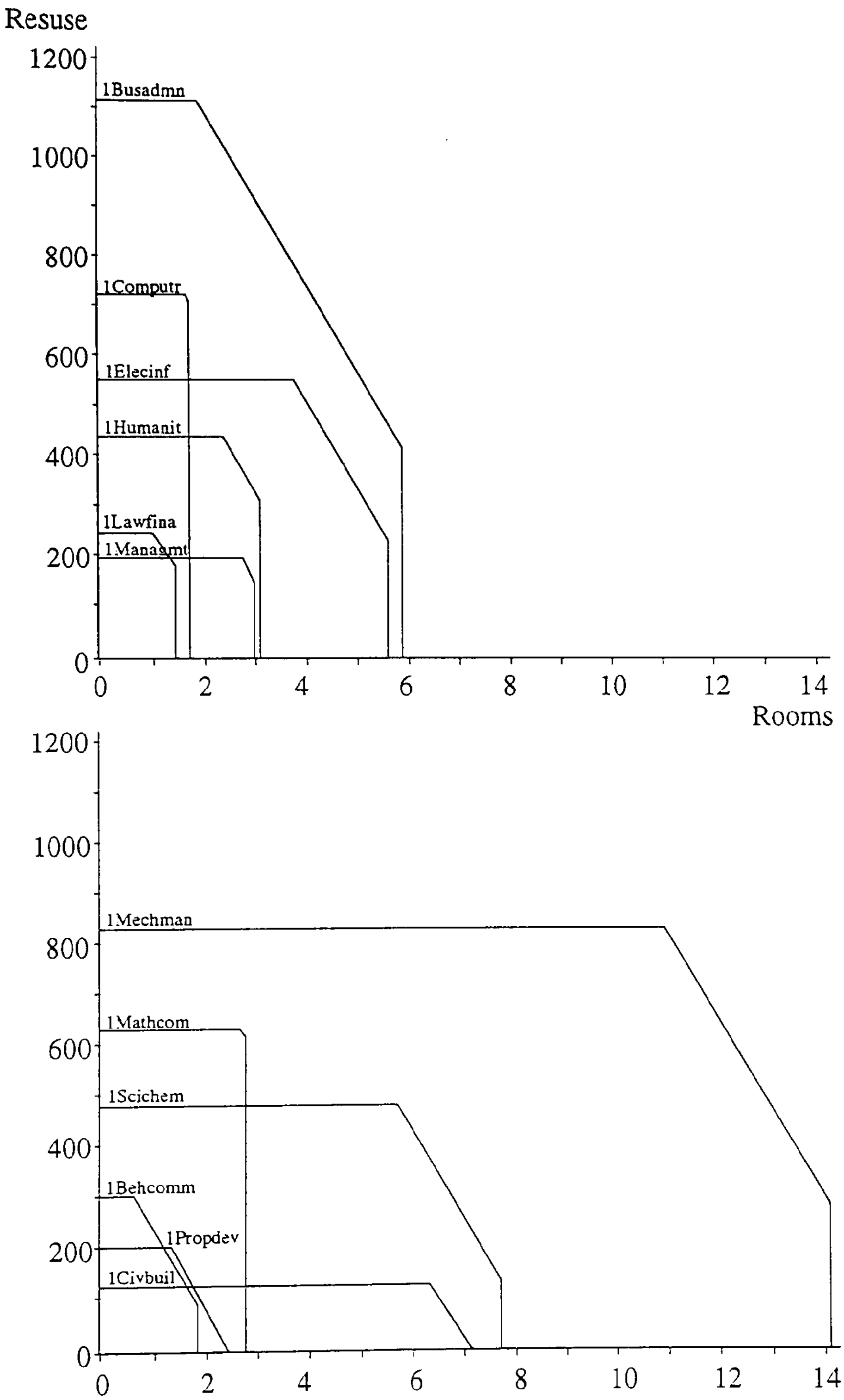

Figure 5.4 Efficiency Zones 1989/90

Using Incgen as the dependent variable identified two independent variables that met the criterion for inclusion although the adjusted R^2 was only 0.34 and Texpwb was not quite significant at the 95% level. Research as the dependent variable produced no variables that fulfilled the inclusion criterion.

5.3 Income & Expenditure

Summarised Income & Expenditure accounts by department for years 1990/91 and 1989/90 are shown in Figures 5.5 and 5.6 with a more detailed version in Appendix D. All university income and expenditure is included and allocated to individual departments on varying bases. The Income and Expenditure accounts provide detailed financial information for each DMU with a wide spread of "bottom line" results from a deficit of £633896 for Management in 1989/90 (scaled for inflation) to a surplus of £910000 for Business and Admin in 1990/91. Although using the "bottom line" figure is somewhat simplistic given the amount of detail available it does provides an indication of the spread of the financial results.

DEPARTMENTAL INCOME AND EXPENDITURE SUMMARY 1990/91

	BUS & ADMIN	HUMAN-ITIES	LAW & FINANCE	MANAGE MENT	LANG. CENTRE
INCOME	£	£	£	£	£
DIRECT	903107	510688	888916	149050	6390
ALLOCATED	2006942	1024631	1085195	356680	64586
TOTAL INCOME	2910049	1535319	1974111	505730	70976
EXPENDITURE					
DIRECT	1039818	623005	935457	547355	279275
ALLOCATED	959900	584313	807426	400162	242862
TOTAL EXPENDITURE	1999718	1207318	1742883	947517	522137
NET INCOME/ (EXPENDITURE)	910331	328001	231228	-441787	-451161

	COMPUTR STUDIES	ELEC & IT	MATHS & COMPUTG	MECH & MAN ENG	BEHAV & COMM
INCOME	£	£	£	£	£
DIRECT	579236	450112	167883	368657	333274
ALLOCATED	1776219	1284783	571634	878743	859372
TOTAL INCOME	2355455	1734895	739517	1247400	1192646
EXPENDITURE					
DIRECT	1127930	1195006	745279	924982	809218
ALLOCATED	828781	848762	536540	769855	644161
TOTAL EXPENDITURE	1956711	2043768	1281819	1694837	1453379
NET INCOME/ (EXPENDITURE)	398744	-308873	-542302	-447437	-260733

Figure 5.5 Summarized Income and Expenditure Account 1990/91

	CIV ENG & BLDG	PROPRTY & DEVT	SCIENCE & CHEM ENG	TOTAL
INCOME	£	£	£	£
DIRECT	687715	359105	662016	6066149
ALLOCATED	2112009	1050461	1974744	15045999
TOTAL INCOME	2799724	1409566	2636760	21112148
EXPENDITURE				
DIRECT	1368349	622044	1566239	11783957
ALLOCATED	1213821	491293	1221533	9549409
TOTAL EXPENDITURE	2582170	1113337	2787772	21333366
NET INCOME/ (EXPENDITURE)	217554	296229	-151012	-221218

Figure 5.5 Cont.

Summarized Income and Expenditure Account 1990/91

DEPARTMENTAL INCOME AND EXPENDITURE SUMMARY 1989/90

	BUS & ADMIN	HUMAN-ITIES	LAW & FINANCE	MANAGE MENT	LANG. CENTRE
INCOME	£	£	£	£	£
DIRECT	299670	268238	499719	57174	8992
ALLOCATED	2037051	940603	1296718	306230	77777
TOTAL INCOME	2336721	1208841	1796437	363404	86769
EXPENDITURE					
DIRECT	588173	336975	371318	420681	168925
ALLOCATED	1283742	841779	870798	528190	266162
TOTAL EXPENDITURE	1871915	1178754	1242116	948871	435087
NET INCOME/ (EXPENDITURE)	464807	30087	554321	-585467	-348319

	COMPUTR STUDIES	ELEC & IT	MATHS & COMPUTG	MECH & MAN ENG	BEHAV & COMM
INCOME	£	£	£	£	£
DIRECT	405371	392084	147887	406501	205700
ALLOCATED	2002963	1459671	653038	1065761	850914
TOTAL INCOME	2408334	1851755	800925	1472262	1056614
EXPENDITURE					
DIRECT	867402	1171314	637889	1068190	765439
ALLOCATED	753434	840981	513688	768321	615961
TOTAL EXPENDITURE	1620836	2012295	1151577	1836511	1381400
NET INCOME/ (EXPENDITURE)	787498	-160540	-350652	-364249	-324787

Figure 5.6 Summarized Income and Expenditure Account 1989/90

	CIV ENG & BLDG	PROPRTY & DEVT	SCIENCE & CHEM ENG	TOTAL
INCOME	£	£	£	£
DIRECT	514773	263418	418409	4253246
ALLOCATED	2120482	1113030	1876607	15435533
TOTAL INCOME	2635255	1376448	2295016	19688779
EXPENDITURE				
DIRECT	1363621	614896	1519441	9888264
ALLOCATED	1171219	492489	1176381	10139145
TOTAL EXPENDITURE	2544840	1107385	2695822	20027409
NET INCOME/ (EXPENDITURE)	90415	269063	-400806	-338630

Figure 5.6 Cont.

Summarized Income and Expenditure Account 1989/90

Total income increased throughout the University from 1989/90 to 1990/91 apart from in the Language Centre and departments in the Faculty of Technology Studies. Direct expenditure remained fairly constant except in the Professional Studies faculty in which there was considerable structural reorganisation during the 1989/90 financial year. Allocated expenditure has increased or remained constant in every department with the most substantial increases being in the Professional Studies faculty.

There is a marked difference between the results for Science and Engineering based departments and other disciplines. The total deficit for Science and Engineering departments is £833323 whilst other departments have an overall surplus of £612111. Science and Engineering departments would be expected to incur greater costs due to the nature of the disciplines and the requirements for laboratory space and technical supervision. However, these departments still incur significant deficits even though varying costs are accounted for in funding allocations with Welsh Advisory Board (WAB) funding being up to 77% higher for some engineering disciplines than it is for Humanities.

5.4 Unit Cost

The unit cost figures for each department are shown in Tables 5.5 and 5.6. These show the cost each department incurs per full time equivalent student including all non direct costs allocated to departments in the income and expenditure accounts. The inflation scaled figures are shown also, to allow comparability across the two years of the analysis. The range here is from £7925 per FTES for Mechanical and Manufacturing Engineering in 1989/90 to £2748 for Business and Admin in 1990/91. The overall cost per FTES for the university is £4040 in 1990/91 and £4227 in 1989/90 (scaled). Science and Engineering departments would be expected to incur above average costs given the nature of the disciplines. This proves to be the case in 5 of the 6 science based departments in 1989/90 and 4 out of 6 in 1990/91. The total cost per student in science and engineering departments in 1990/91 was £5031 compared to £2827 for non science departments.

Department	Total Cost (£)	FTES	Unit Cost (£)
Business & Admin	1999718	728	2747.62
Humanities	1207318	381	3170.48
Law & Finance	1742883	608	2868.47
Management	947517	241	3936.51
Computer Studies	1956711	530	3694.00
Electronics & IT	2043768	358	5712.04
Maths & Computing	1281819	298	4307.19
Mech. and Man. Eng.	1694837	281	6042.20
Behavioural & Comm.	1453379	434	3347.26
Civ. Eng. & Building	2582170	499	5170.54
Property & Devt	1113337	279	3989.02
Science & Chem. Eng.	2787772	489	5700.97
Total	21333364	5281	4039.57

Figure 5.5 Unit Cost Summary 1990/91

Department	Total Cost (£)	FTES	Unit Cost (£)	Scaled Unit Cost (£)
Business & Admin	1871914	625.4	2993.15	3240.74
Humanities	1178753	370.3	3183.24	3446.55
Law & Finance	1242115	573.3	2166.61	2345.83
Management	948871	214.4	4425.70	4791.79
Computer Studies	1620836	544.6	2976.20	3222.38
Electronics & IT	2012295	382.7	5258.15	5693.10
Maths & Computing	1151576	318.6	3614.49	3913.48
Mech. and Man. Eng.	1836510	250.9	7319.69	7925.17
Behavioural & Comm.	1381400	419.7	3291.40	3563.66
Civ. Eng. & Building	2544839	506	5029.33	5445.35
Property & Devt	1107384	292.9	3780.76	4093.50
Science & Chem. Eng.	2695822	485.8	5549.24	6008.27
Total	20027409	5130	3903.83	4226.75

Figure 5.6 Unit Cost Summary 1989/90

5.5 FEMIS Ratios

Ratios based on the Further Education Management Information System (FEMIS) are shown in table 5.7. The data is quite difficult to interpret as it requires the simultaneous consideration of a number of different factors to give an overall profile for each department. The most commonly cited of these ratios is the staff-student ratio (SSR). The highest of these is 20:1 for Business and Admin in 1990/91 which is partially explained by the highest Average Class Size (ACS) of 22.5 also being recorded for that department. It is difficult to conclude whether achieving the highest score in those two ratios is a positive performance as they are also combined with lower student and lecturer hours than the University average thus indicating a high throughput of students with quite low contact time. The range of ratios recorded is substantial with some SSRs as low as 10.2:1. Average Lecturer hours range from 7.2 to 20.2 hours per week in 1989/90 alone although these two figures are extreme and the same range does not occur in the following year. Once more, there is a distinct difference between science and engineering and other disciplines with a tendency for lower SSRs and higher student hours in those departments. This again can largely be explained by the nature of the science and engineering disciplines and the amount of practical work required.

1990/91				
DEPARTMENT	SSR	ACS	ALH	ASH
2BUSADMN	20	22.5	13.3	14.9
2HUMANIT	16.6	16	12.2	11.8
2LAWFINA	16.5	21.2	12.8	16.4
2MANAGMT	13.5	15.5	13.6	15.6
2COMPUTR	13.5	16.1	12.7	15.2
2ELECINF	10.8	14.4	13.3	17.9
2MATHCOM	12.2	19.1	11.8	18.5
2MECHMAN	13.9	17	15.6	19.1
2BEHCOMM	15.6	17.5	12.9	14.5
2CIVBUIL	12.6	18.4	13.7	20.1
2PROPDEV	14.5	15.2	15.4	16.1
2SCICHEM	12.3	15.4	14.9	18.7
UNIVERSITY TOTAL	14.2	17.5	13.5	16.6

1989/90				
DEPARTMENT	SSR	ACS	ALH	ASH
1BUSADMN	18.5	18	13.1	12.8
1HUMANIT	14.9	15.5	11.6	12
1LAWFINA	18.5	19.5	13.5	14.2
1MANAGMT	10.2	19.2	7.2	13.6
1COMPUTR	16	16.4	15.9	16.3
1ELECINF	14	12.9	20.2	18.6
1MATHCOM	12.8	19.4	12.3	18.6
1MECHMAN	11.6	18.5	13.4	21.4
1BEHCOMM	14.9	16.9	11.9	13.6
1CIVBUIL	13.2	14.8	16	18
1PROPDEV	15.4	14	16.9	15.3
1SCICHEM	12.3	12.1	17.3	16.9
UNIVERSITY TOTAL	12.9	16.9	13.4	17.5

KEY TO RATIOS:
SSR Student Staff Ratio
ACS Average Class Size
ALH Average Lecturer Hours
ASH Average Student Hours

For department abbreviations see Appendix C.

Table 5.7 FEMIS Ratios

5.6 DEA Results

5.6.1 Introduction

In considering the University of Glamorgan results, the main emphasis will be on output oriented models although input-orientation will be considered.

The results of the tests for variable returns to scale show a correlation of -0.493 between ranked efficiency and scale. The scatterplot of constant returns to scale efficiency against full-time equivalent students is shown in figure 5.7. There is a slight detectable trend in figure 5.7 which indicates that the variable returns to scale model may provide some insight beyond the CRS model but as neither this nor the correlation were particularly conclusive the following analysis will focus principally on the CRS results.

For ease of interpretation, the different models will be referred to as follows:-

CI - Constant returns to scale, input-orientation.
CO - Constant returns to scale, output-orientation.
VI - Variable returns to scale, input-orientation.
VO - Variable returns to scale, output-orientation.

The principal analysis of the University of Glamorgan DEA results will concentrate on CO and VO models.

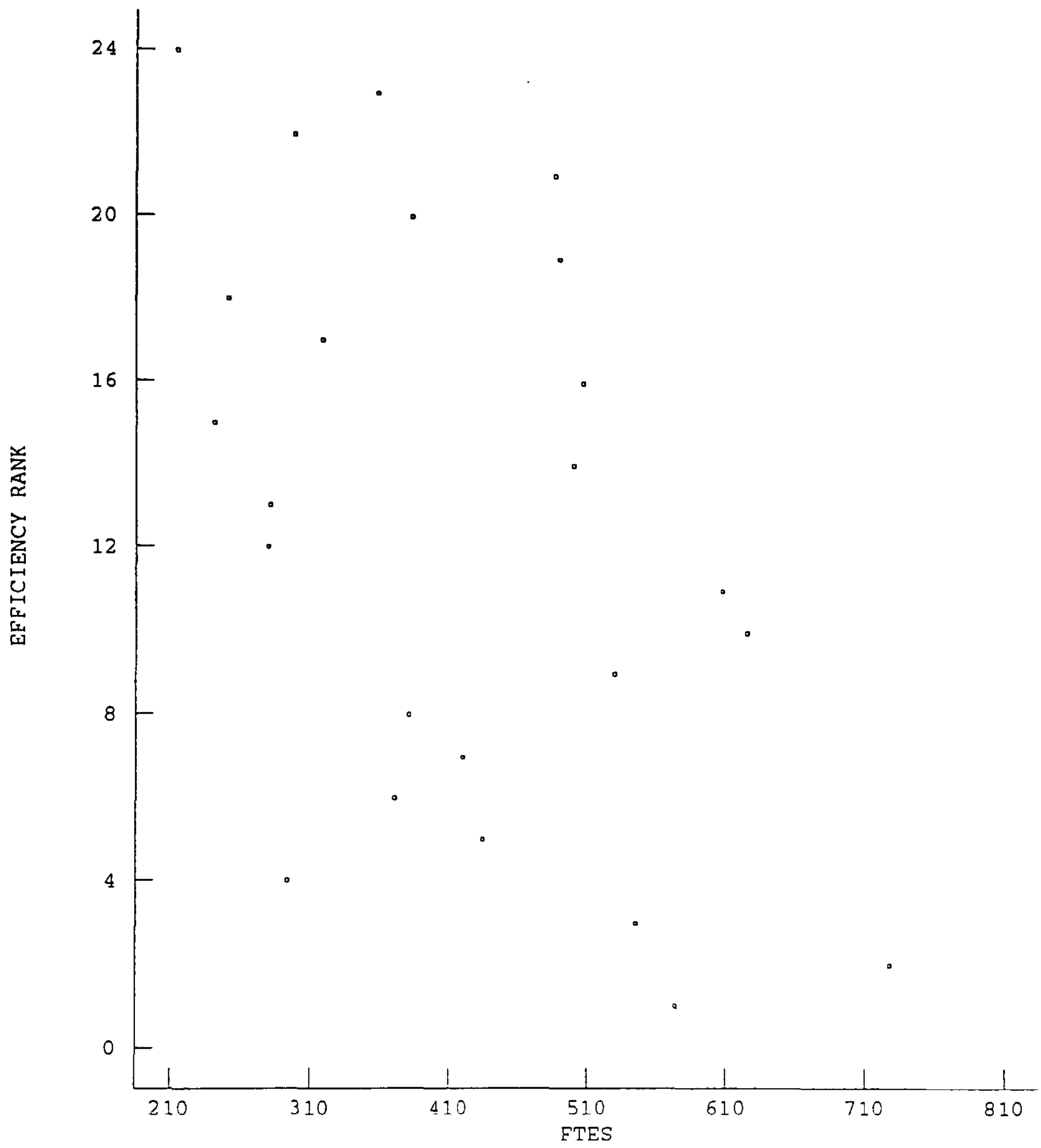

Figure 5.7 Returns to Scale Scatterplot

5.6.2 CO Results

The results of the CO model are summarised in table 5.8. The complete data set used for all DEA models is contained in Appendix E. The departments are ranked in order of efficiency with the most efficient first. The efficiency scores give a rating of between 0 and 1. Departments on the efficient frontier are ranked by virtue of the number of times each are referred to in the reference sets of inefficient departments. This forms the final column of the table.

RANK	DEPARTMENT	EFFICIENCY SCORE	REFERENCE SET QUOTATIONS
1	1LAWFINA	1	17
2	2BUSADMN	1	15
3	1COMPUTR	1	4
4	1PROPDEV	1	2
5	2BEHCOMM	1	1
6	1HUMANIT	0.954	-
7	1BEHCOMM	0.916	-
8	2HUMANIT	0.912	-
9	2COMPUTR	0.912	-
10	1BUSADMN	0.893	-
11	2LAWFINA	0.882	-
12	2PROPDEV	0.844	-
13	2MECHMAN	0.798	-
14	2CIVBUIL	0.731	-
15	2MANAGMT	0.719	-
16	1CIVBUIL	0.697	-
17	1MATHCOM	0.639	-
18	1MECHMAN	0.634	-
19	2SCICHEM	0.572	-
20	1ELECINF	0.560	-
21	1SCICHEM	0.559	-
22	2MATHCOM	0.527	-
23	2ELECINF	0.495	-
24	1MANAGMT	0.493	-

Table 5.8 CO Model Results Summary

Five departments are shown as efficient in the CO model, of which three are in 1989/90. The least efficient departments are Management Studies in 1989/90 (1Managmt) and Electronics and Information Technology in 1990/91 (2Elecinf) with relative efficiency scores of 49%. The detailed results for 2Elecinf are shown in table 5.9. The information produced shows the results achieved by 2Elecinf for each variable and the results required for the department to become efficient. The weight column shows the relative weight applied to each variable in attaining the most favourable efficiency score. The weights shown for the variables in 2Elecinf were the same as those identified for 10 other inefficient departments in the analysis and in all of these cases the reference set comprised 2Busadmn and 1Lawfina.

Department: 2Elecinf | Model: CO

Efficiency Score = 0.495 | Scaling Factor = 2.02

Outputs	Observed	Projected	Slack	Weight
Income (£) Generated	1458392	2947550	0	1
Scholarly Activity	17.67	40.38	4.67	1
Value Added	415.5	839.7	0	50.64

Inputs	Observed	Projected	Excess	Weight
Total (£) Expenditure	1367758	1367758	0	2.456
Room Space	2165.5	1337.6	827.9	1

Reference Set

Department	Weight
2Busadmn	0.6233
1Lawfina	0.7025

Table 5.9 2Elecinf DEA Results - CO Model

The reference set and the weightings on each department in the set are used to calculate the projected levels for each variable. The condition for a department being part of the reference set are that the weights applied to the variables for the department in the analysis produce an efficiency score of one when applied to the departments in its reference set. This reference set is said to envelope the department being analysed. The projected profile for the inefficient department is thus a weighted combination of the performance of the departments enveloping it. The efficiency score is calculated through comparison between the observed and projected values for each output variable (as illustrated in Chapter Three).

The variables used in the DEA models are constructed from highly detailed data. Table 5.10 shows the data for 2Elecinf for each variable whilst table 5.11 contains data for 1Lawfina. Consideration of how the variables are constructed may give a greater insight into the reasons for efficiency or inefficiency in a department, and why some variables are more favourable than others. 1Lawfina is the most efficient department in the model and has the largest weighting of the departments in the reference set for 2Elecinf. Considering the data for 1Lawfina alongside that of 2Elecinf may help make relative efficiencies and inefficiencies more apparent.

The income generated figure consists mainly of Welsh Advisory Board (WAB) income. This income is allocated to Welsh universities in accordance with projected numbers of home students in different disciplines. Some disciplines receive higher income weights than others. Electronics and Information Technology is one of the most highly weighted programme areas in terms of income per student, hence the WAB income is such a large proportion of total income generated for this department (69%). In comparison to the university average, 2Elecinf's income generated is 17% higher although the weight assigned to this variable by DEA is only 1.0, the lowest weight that can be allocated by the CO model. 1Lawfina's income generated is considerably higher at £1.8m (after scaling for inflation). One major factor contributing to this higher level of income is that total overseas students fees for Law and Finance are 3 times that of 2Elecinf. Also in 1989/90, home fees were much lower overall than in 1990/91, therefore 1Lawfina's WAB allocation was similar to 2Elecinf's even though 2Elecinf's WAB weighting is much higher, and the level of home fees for the two departments are similar.

Income Generated	2Elecinf	Per FTES	University per FTES
	£	£	£
Fees: Home	349861		
Overseas	99387		
WAB Income	1008280		
Misc. Income	854		
Total Income Generated	1458392	4076	3478.5

Total Expenditure	£	£	£
Gross Expenditure	1195006		
LRC/ITC Allocation	172752		
Total Expenditure	1367758	3347	2231

Room Space		Per FTES	University per FTES
	m^2	m^2	m^2
Lecture rooms	484.3		
Staff Rooms	434.5		
Laboratories/Workshops	1153.0		
Other	93.7		
	2165.5	6.05	3.91

Scholarly Activity	Calendar Year 1990	Calendar Year 1991	Academic Year 1990/91	Per FTEL	University per FTEL
Publications	17	7	10.33	0.31	0.45
Conference Papers	14	2	6	0.18	0.24
Research Degrees	2	1	1.33	0.04	0.02
Total	33	10	17.67	0.53	0.71

Value Added Data		2Elecinf	University
Average Entry (A level pts)		6.95	8.33
Average Exit (Grade pts *	F/T	945.8	1059.7
Credit pts)	P/T	865.1	627.1
Average Wastage (%)	F/T	8.5	10.7
	P/T	15.1	12.4
Value Added per Student		1.161	1.0
FTES		357.8	
Total Value Added		415.4	

Table 5.10 Data for DEA Variables - 2Elecinf

Income Generated	1Lawfina	Per FTES	University per FTES
	£	£	£
Fees: Home	300027		
Overseas	279696		
WAB Income	1080153		
Misc. Income	2482		
Total Income Generated	1662358		
Inflation Scaled Total	1799866	3139.5	3610.6
(RPI Weighting = 1.082719)			
Total Expenditure	£	£	£
Gross Expenditure	620483		
LRC/ITC Allocation	132971		
Total Expenditure	753454		
Inflation Scaled Total	815779	2710.9	1422.9
Room Space		Per FTES	University per FTES
	m^2	m^2	m^2
Lecture rooms	481.3		
Staff Rooms	348.0		
Laboratories/Workshops	0		
Other	12.3		
	841.6	1.47	4.02

Scholarly Activity	Calendar Year 1990	Calendar Year 1991	Academic Year 1990/91	Per FTEL	University per FTEL
Publications	14	28	23.33	0.75	0.55
Conference Papers	13	15	14.33	0.46	0.43
Research Degrees	-	-	-	-	0.04
Total	27	43	37.67	1.21	1.02

Value Added Data		1Lawfina	University
Average Entry (A level pts)		12.63	8.33
Average Exit (Grade pts *	F/T	1159.9	1053.4
Credit pts)	P/T	-	644.2
Average Wastage (%)	F/T	11.8	12.3
	P/T	-	16.9
Value Added per Student		0.731	1.0
FTES		573.3	
Total Value Added		418.79	

Table 5.11 Data for DEA Variables - 1Lawfina

Scholarly activity for academic year 1990/91 was obtained by taking appropriate portions of the 1990 and 1991 totals. Electronics and Information Technology demonstrated a significant decrease in activity across these two years. This decrease, with two-thirds of the 1990/91 scholarly activity measure based on 1991, results in total scholarly activity for 2ELecinf being only 75% of the university average per full-time member of staff. This may contribute to 2Elecinf's inefficiency. Scholarly activity for this department has slack of 4.67, a further 26% increase in addition to the 102% advocated by the efficiency score. Over 1989 and 1990, Law and Finance displayed an increase in scholarly activity with more of both publications and conference papers. The department's total for 1989/90 was 1.39 units per FTEL, the university average being 1.03 for that year.

The value added data is more positive and this is reflected by the weight allocated to this variable (the highest of all 2Elecinf's variables) indicating that it is the most favourable variable for this department. Average entry points (A level) per student were 83% of the university average at 6.95 per student. The average exit score (comprised of grade points and credit points multiplied together) is 946. This is less than average for full-time students. The part-time exit score, at 865, is greater than average. The final value added score of 116% demonstrates however, that the shortfall in exit score for full-time students is less than expected given the entry score.

The value added score has an in-built university comparison in its construction, a score of greater than 100% being better than the overall university score. On this variable, 2Elecinf outperforms 1Lawfina. Entry scores for Law and Finance average 12.6 per student, more than 50% above the university average, whilst exit scores are only very slightly above average. This leads to a value added score of only 73% per student for 1Lawfina.

The most highly weighted input variable for 2Elecinf is Total Expenditure. The figures for this variable however, demonstrate significant differences between 2Elecinf and university-wide performance. The direct expenditure total is 50% higher than the university average. Although central funding is higher for this discipline on the basis that it costs more, income generated was only 17% higher than average. Costs allocated for use of the Information Technology Centre are relatively high because of the obviously large technical content of subjects in this department. Total expenditure for Law and Finance in 1989/90 is only £1422 per FTES (after scaling), which is considerably lower than 2Elecinf.

The room allocation figure also gives a very negative picture for Electronics and Information Technology with total room use 55% higher per student than other departments and still 32% higher than departments in the same faculty. The room types that are most highly used in comparison to the rest of the university are staff rooms and special facilities rooms, which for 2Elecinf would be Electronics and Computing laboratories. Room space has an input excess of 828m^2 for 2Elecinf.

After considering performance in all variables, the reasons for 2Elecinf's poor DEA result are clear. Only the Valadd variable produced a better than average result. As DEA uses a frontier method rather than an average, an overall performance of better than average may still be insufficient for DEA efficiency.

Comparing 2Elecinf to its reference set, both 2Busadmn and 1Lawfina have identical weights to 2Elecinf for their variables. Even though Valadd, 1Lawfina's weakest variable has the highest weighting, Law and Finance in 1989/90 is still reported as the most efficient department.

The same detailed analysis can be applied to all departments in a DEA run, although it is most pertinent for the inefficient departments. The analysis of 2Elecinf results serves as an example of the potential for interpretation.

5.6.3 VO Model

Allowing for variable returns to scale involves one further constraint in the linear programme. This constraint requires that the weightings on the departments in the reference set must sum to one. This ensures that results from efficient departments are not projected beyond the scale at which they operate. The results produced have the same amount of detail but the efficiency score shown can only be the same or higher than with the constant returns to scale model. Hence the improvement potential for a particular department will be the same or less than when assuming constant returns to scale. The rankings of departments can deteriorate however as although efficiency scores can only stay constant or improve, the relative position of each department may differ either way.

The results of the variable returns to scale model reported four further departments as efficient bringing the total to nine and whereas previously 1Lawfina was the most efficient department enveloping 17 others in the CRS model, it is now the 4th most efficient department and envelopes only 5 others. In the CRS model, 1Lawfina was sometimes given a weighting of greater than one in the reference set but this can no longer happen with the VRS version. The most efficient department is now 2Busadmn followed by 2Managmt and 1Computr. The assumption of scale efficiency is no longer imposed which means that inefficient departments are compared with those departments that truly envelop them and not those that would envelop them when projecting their values to the appropriate scale.

VRS RANK	DEPT	VRS EFFICIENCY SCORE	REFERENCE SET QUOTATIONS	CRS EFFICIENCY SCORE
1	2BUSADMN	1	10	1
=2	1COMPUTR	1	8	1
=2	2MANAGMT	1	8	0.719
4	1LAWFINA	1	5	1
=5	1HUMANIT	1	2	0.954
=5	1SCICHEM	1	2	0.559
=7	2BEHCOMM	1	1	1
=7	1PROPDEV	1	1	1
=7	2PROPDEV	1	1	0.844
10	2LAWFINA	0.985	-	0.882
11	1ELECINF	0.949	-	0.560
12	1BEHCOMM	0.933	-	0.916
13	2HUMANIT	0.933	-	0.912
14	2COMPUTR	0.933	-	0.912
15	1BUSADMN	0.911	-	0.893
16	1CIVBUIL	0.880	-	0.697
17	2CIVBUIL	0.853	-	0.731
18	2MECHMAN	0.845	-	0.798
19	2SCICHEM	0.832	-	0.572
20	1MANAGMT	0.823	-	0.493
21	1MECHMAN	0.742	-	0.634
22	1MATHCOM	0.669	-	0.639
23	2MATHCOM	0.608	-	0.527
24	2ELECINF	0.581	-	0.495

Table 5.12 Comparison of CRS and VRS Results

Table 5.12 illustrates how VRS and CRS results compare. Two of the most notable changes are the department of Management Studies in 1990/91 changing from 15th place and an efficiency score of 72% under CRS to joint 2nd place under VRS and the department of Science and Chemical Engineering which changed from 56% and 21st place to 5th most efficient department under VRS.

The efficiency score for 2Elecinf is now 58% (previously 49.5%) and the projected results are quite different (see table 5.13). The reference set comprises 2Busadmn, 1Scichem and 1Computr. The highest weighted variables are scholarly activity and value added whereas under the CRS model they were value added and total expenditure. This illustrates that the most highly weighted variables are not necessarily those on which a department performs best overall, but those which produce the best result in comparison to its reference departments.

Department: 2Elecinf Model: VO

Efficiency Score = 0.581 Scaling Factor = 1.72

Outputs	Observed	Projected	Slack	Weight
Income (£) Generated	1458392	2512592	201	1
Scholarly Activity	17.67	30.42	0	49352
Value Added	415.5	715.2	0	2319

Inputs	Observed	Projected	Excess	Weight
Total (£) Expenditure	1367758	1367758	0	1
Room Space	2165.5	1398.7	766.8	1

Reference Set

Department	Weight
2Busadmn	0.4813
1Scichem	0.1190
1Computr	0.3997

Table 5.13 2Elecinf DEA Results - VO Model

Projected values for 2Elecinf are less dramatic in all cases, as would be expected with a 72% increase diagnosed compared to the 102% proposed by the CRS model. The only slack is £2014 on income generated, an almost negligible amount when compared to the actual total of over £1.45 million. The output slack on scholarly activity with the CRS model was far more significant at 26% of the observed value.

The results projected for the input variables are very similar to the CRS results. Neither have input excess on total expenditure and the projected values for room space differ by only 61m^2.

The principal differences between constant and variable returns to scale models are the higher efficiency scores and the less severe projected values with VRS with some departments improving quite dramatically with the removal of the assumption of constant returns to scale.

5.6.4 CI Model

Department: 2Elecinf   Model: CI

Efficiency Score = 0.495

Outputs	Observed	Projected	Slack	Weight
Income (£) Generated	1458392	2947550	0	1
Scholarly Activity	17.67	19.98	2.31	1
Value Added	415.5	415.5	0	50.64

Inputs	Observed	Projected	Excess	Weight
Total (£) Expenditure	1367758	676741	0	2.46
Room Space	2165.5	661.8	409.6	1

Reference Set

Department	Weight
2Busadmn	0.3084
1Lawfina	0.3476

Table 5.14 2Elecinf Results - CI Model

The input oriented constant returns to scale model produces identical efficiency scores to the CO model. The same departments are contained in the reference sets, although with different weightings, hence the departments ranks are identical also.

The CI results for 2Elecinf as shown in table 5.14 show very little slack on outputs, with the only increase projected being 2.31 (13%) for Scholarly Activity. Reductions in inputs suggested are greater than 50% with an excess of 410m2 for Room space giving a total proposed reduction of 69% for that variable.

5.6.5 VI Model

There is a greater difference between the results of input and output oriented models when using variable returns to scale than there is when the CRS model is used. This is because of restrictions in the reference set weightings. Using CRS, the same ratios are produced with input and output orientation but with different weightings in the reference set. If these reference set weights are restricted as in VRS, then the input and output orientations produce different ratios. The results are not hugely different however, with a correlation of 0.67 at 99.97% significance and the rankings are very similar. One notable difference is the Department of Management Studies in 1989/90 (1Managmt) which is efficient according to the efficiency score but has substantial slacks or excesses in four variables. The VI results for 1Managmt are shown in table 5.15. The reason for its 100% score is that its performance in the Room space variable is not enveloped by any other departments actual performance and is only matched by 2Managmt. Therefore as no improvement can be projected for that variable the input oriented efficiency score must be 100%. This situation has only arisen in the VI model because decreases in inputs are not taken into account when calculating output oriented efficiency scores, and if constant returns to scale were assumed then a lower figure for Room space can be projected than is actually observed in any department. This projected figure would be formed by summing appropriate proportions of the figures observed in those larger departments, with suitable input-output relationships, that form the reference set. In a variable returns to scale model these proportions must sum to one, whereas for 1Managmt in the CI model these summed to 0.3.

Department: 1Managmt   Model: VI

Efficiency Score = 1.000

Outputs	Observed	Projected	Slack	Weight
Income (£) Generated	306220	420317	114097	1
Scholarly Activity	10	18	8	1
Value Added	182.9	222.1	39.2	1

Inputs	Observed	Projected	Excess	Weight
Total (£) Expenditure	684360	580505	103854	1
Room Space	603.4	603.4	0	481.33

Reference Set

Department	Weight
2Managmt	1

Table 5.15 1Managmt DEA Results - VI Model

The results of the VI and CI models for 2Elecinf (table 5.16) are very alike, although the efficiency score is slightly higher with variable returns to scale, as expected. The most notable difference is a much larger slack in Scholarly activity with VRS.

Department: 2Elecinf Model: VI

Efficiency Score = 0.585

Outputs	Observed	Projected	Slack	Weight
Income (£) Generated	1458392	1458392 (1458392)	0 (0)	1 (1)
Scholarly Activity	17.67	28.91 (19.98)	11.24 (2.31)	1 (1)
Value Added	415.5	415.5 (415.5)	0 (0)	2468 (50.64)

Inputs	Observed	Projected	Excess	Weight
Total (£) Expenditure	1367758	799790 (676741)	0 (0)	26.48 (2.46)
Room Space	2165.5	810.3 (661.8)	455.9 (409.6)	1 (1)

Reference Set

Department	Weight	
2Busadmn	0.1383	(0.3084)
1Lawfina	0.5240	(0.3476)
2Managmt	0.3377	(-)

Figures in brackets are a comparison of CI results

Table 5.16 2Elecinf DEA Results - VI Model

A comparison of input and output oriented results under VRS shows quite similar results for 2Elecinf although the reference sets are very different.

5.6.6 Sensitivity Analysis

5.6.6.1 Removing Efficient Units

There are three stages to this part of the sensitivity analysis as explained in the methodology chapter. Each stage involves the removal of the most efficient remaining department and considering the effect of its removal on other departments. The CO model has been used for all stages.

Department	Full DMU Set	Exc. 1Lawfina	Exc. 1Lawfina 2Busadmn	Exc. 1Lawfina 2Busadmn 2Humanit
2Busadmn	1	1	-	-
2Humanit	0.912	1	1	-
2Lawfina	0.882	0.898	0.943	0.944
2Managmt	0.719	0.862	0.883	0.897
2Computr	0.912	0.912	0.929	0.929
2Elecinf	0.495	0.517	0.630	0.632
2Mathcom	0.527	0.533	0.674	0.677
2Mechman	0.798	0.816	1	1
2Behcomm	1	1	1	1
2Civbuil	0.731	0.759	0.891	0.892
2Propdev	0.844	0.923	1	1
2Scichem	0.572	0.588	0.733	0.735
1Busadmn	0.893	0.893	1	1
1Humanit	0.954	1	1	1
1Lawfina	1	-	-	-
1Managmt	0.493	0.527	0.571	0.575
1Computr	1	1	1	1
1Elecinf	0.560	0.634	0.659	0.714
1Mathcom	0.639	0.720	0.789	0.801
1Mechman	0.634	0.665	0.761	0.792
1Behcomm	0.916	0.926	0.926	0.926
1Civbuil	0.697	0.726	0.850	0.852
1Propdev	1	1	1	1
1Scichem	0.559	0.594	0.655	0.706

Table 5.17 Effect of Removing Efficient DMUs

The effect of these changes are shown in table 5.17. The first stage was to remove Law and Finance for 1989/90 which was contained in the reference set of seventeen departments. This caused two previously inefficient departments to become efficient (Department of Humanities 1989/90 and 1990/91). Fifteen inefficient departments improved and two remained the same (the only two inefficient departments which did not contain 1Lawfina in their reference sets). The largest efficiency increase was of 0.143 for 2Managmt. The weights allocated to certain variables increased considerably. Although the results projected from the efficiency scores are less severe, there are also some adverse changes in slacks and excesses. These are to the extent that in four departments, the projected Value added figures were higher than when 1Lawfina was in the reference set because of increases in slack. Room space showed less consistent results with excess decreasing in seven departments and increasing in two. The effect on 2Elecinf was an increase in efficiency score of 0.02 to 52% with projected figures for all output variables being slightly lower.

The second stage was to remove Business and Administrative Studies for 1990/91 which was in the reference set of thirteen departments in the original analysis and in seventeen departments (i.e all inefficient departments) when 1Lawfina was removed. The effect of removing 2Busadmn was for three departments to become efficient, five to remain efficient and fourteen to improve. Again, although efficiency scores improved, higher outputs were projected in some cases due to increased slack. This occurred in six cases with Scholarly activity and four cases with Income generated. Whereas when 1Lawfina was removed there were increases in weights allocated to variables, changes in weights were less consistent at this stage. Changes in 2Elecinf were greater at this stage with an increase in efficiency score of 0.11 to 63%. The reference set has changed from 2Busadmn and 1Propdev to 2Humanit and 1Busadmn. The scholarly activity variable projection has worsened with the change in reference set and now has a large slack.

The final stage was to remove the Department of Humanities for 1990/91. This department was only 91% efficient in the original analysis, became efficient when 1Lawfina was removed and when 2Busadmn was removed formed part of the reference set for twelve departments, thus becoming the most efficient department at that stage. Removing 2Humanit caused twelve inefficient departments to improve and two to remain the same. No departments became efficient at this stage. All improvements in efficiency were small with the largest improvement being 0.055 for 1Elecinf. The most efficient department at this stage is 1Busadmn which is in the reference set for all but one of the inefficient departments. Room space excess increases in eight cases but there are no notable changes in any other variables. 2Elecinf displayed an extremely small increase in efficiency (0.002). Scholarly activity slack has reduced considerably but there is a much larger excess in Room space.

After the third department was removed the changes in results were much smaller with an almost negligible increase in efficiency scores and no new departments becoming efficient. The greatest changes were in the second stage with the removal of 2Busadmn. Three departments became efficient at this stage and all other inefficient departments improved. The changes in each stage show to an extent the characteristics of the departments being removed. For example, removing 1Lawfina, a department with good performance in Room space but poor in Value added, produced increases in Value added projections and decreases in Room space excess in numerous departments. The characteristics of the most efficient departments remaining are also shown. Slack on scholarly activity increased at stage two when 2Humanit became the most efficient department. Scholarly activity is one of the strongest variables in the Humanities department. When 2Humanit was removed, 2Elecinf showed an improvement in its projections for scholarly activity although the inclusion of departments with low room use in its reference set (1Computr and 1Busadmn) caused this variable to display a considerable excess.

5.6.6.2 Removing Variables

The second part of the sensitivity analysis involves removing each variable from the analysis in turn and identifying the effect of its removal on the CO results. The following sections describe the effects of each of these changes.

Removing Income Generated

The results of the model without the income generated variable are very similar to the original results with a highly significant correlation of 0.94 (Sig T <0.0001). Only seven departments show any changes with Scholarly activity slack decreasing in six of these. Of the seven departments which demonstrate a change, the same reference set departments occur in five. 2Elecinf's efficiency score decreased by 0.013 and the excess on the Room space variable increased very slightly although there ceased to be any Scholarly activity slack with Income generated removed.

Removing Scholarly Activity

Changes are observed in fifteen departments when scholarly activity is removed. Two of these departments actually become inefficient. The correlation with the original results is still high however at 0.81 (Sig T <0.0001). There is an increase in Room space excess in ten departments. The results for 2Elecinf do not change when scholarly activity is removed.

Removing Value Added

The correlation with the original analysis here is 0.86 (Sig T <0.0001) although there are quite considerable decreases in efficiency for some departments. Changes are observed in seventeen departments with slack on income generated affected in fifteen of these. Adverse changes in projections for scholarly activity and room space are noted in nine and eleven cases respectively. There is only a small deterioration in the efficiency score for 2Elecinf although there is a large increase in scholarly activity slack.

Removal of Room Space

Efficiency scores in seven departments worsen when room space is removed with two departments becoming inefficient. Correlation is still high at 0.94 (Sig T <0.0001). Neither the decreases in efficiency or any changes in slacks or excesses are particularly dramatic. The results for 2Elecinf are unchanged from the original analysis.

Removal of Total Expenditure

The effect of removing the total expenditure variable is by far the most profound with some quite extreme reductions in efficiency scores (from 80% to 27% for 2Mechman, 73% to 22% for 2Civbuil). The correlation here is the lowest of all the variable removals at 0.59 (Sig T 0.024). Some departments are also allocated huge income generated slacks with projected income generated figures as high as £10.6 million for 2Civbuil. The departments with the large efficiency score decreases and high income generated slacks are those which have very high room space use. 2Elecinf's efficiency score decreases from 49.5% to 28.7% with the removal of the total expenditure variable but there are no changes in slacks or excesses.

The consequences of removing variables are predictable in certain ways. Where slack exists on a variable in the original analysis, then removing that variable will not alter the results for that department as it is allocated a weighting so low as to make it almost negligible. The most profound effects may often be on slacks and excesses. Even where an efficiency score worsens, the overall projections may be better because of reductions in slack and excess. This occurs in 2Propdev when income generated is removed.

5.6.6.3 Summary of Sensitivity Analyses

The two methods of sensitivity analysis showed different trends in results. When enveloping departments were removed from the analysis the efficiency scores could only remain the same or increase as it increases the weighting flexibility for remaining departments. When variables are removed, the efficiency scores of departments can only remain the same or deteriorate as opportunities for identifying aspects of efficiency are removed.

Although the trends in efficiency scores were easily predictable, the effect on slacks and excesses was less so. The changes in these were as a result of different departments appearing in reference sets and with different relative weightings. Each department achieves its efficiency rating by placing emphasis on the most positive aspects of its performance. Hence a change in reference set will identify different areas of an inefficient departments performance as being poor.

5.7 Summary

This chapter has presented an analysis of the results of five performance measurement techniques applied to the University of Glamorgan for the academic years 1989/90 and 1990/91. Investigation of the DEA results involved a breakdown of individual department's results and analysis of four different models with input and output orientation and constant and variable returns to scale.

This chapter contained no qualitative analysis of the information produced, however. A more detailed investigation of the relative quality of the results produced by each technique is presented in the following chapter.

DISCUSSION

6.1 Introduction

It is important, before evaluating the performance measurement techniques applied in this study, to review the context of this evaluation.

Outputs in education are difficult to specifically identify and quantify. As described in Chapter One, the outputs of higher education can be split into various categories with measurement in this study confined within the teaching and research functions. The evaluation of research involves the problem of defining research output whether it is by numbers of publications, research degrees awarded or by a financial measure such as research grants. The evaluation of teaching here focuses on the human capital function (Johnson 1974), more specifically on the value added to students in higher education. When trying to estimate the relative performance of students in departments, one factor that may influence the results is the difficulty of making cross-discipline comparisons. Different subjects have varying marking traditions and teaching methods as well as different course structures and divergent resource requirements. Engineering and technologically based subjects are much more expensive than the humanities or business related disciplines, hence courses in these are at a disadvantage in any cost based analysis of performance. It is obviously necessary to make allowances for differences in cost but it is equally important that the distinction between real differences in cost and actual inefficiency does not become blurred.

For any analysis of performance to be useful it is vital that it is linked to specific objectives. The objectives within and across different departments can (and do) vary. Although there is a common mission statement, interpretation and emphasis on various aspects of this may differ. One department's head may consider research as a more vital output whilst teaching may take priority for another. Quantity of output may be considered more worthwhile than quality in some departments and vice versa. The fulfilment of objectives or "effectiveness" is, thus, a key element in performance measurement but the incongruence of objectives within an institution can make the definition of an appropriate model extremely problematic. The interviews with department heads did produce evidence of a sufficient congruence of objectives in the University of Glamorgan to make the study feasible but this may not always be the case.

In a similar vein, the performance measurement methods themselves need to be examined in relation to certain objectives in order to establish the effectiveness of each method. The hypothesis of this study is that DEA can provide more useful, detailed information on the efficiency of academic departments than conventional methods. Conclusions on this hypothesis can be drawn through a detailed discussion and comparison of the application and results of each method. This will include the analysis of each individual technique with regard to the criteria detailed in section 6.3.

6.2 Evaluation of Methodology

6.2.1 DEA Methodology

One of the initial stages of applying DEA is the selection of decision making units (DMUs). The requirements for this are that the DMUs in the analysis should be sufficiently homogeneous, which means that they should be involved with the same tasks under the same market conditions with very similar objectives. Although the hypothesis of this study specifies analysis at department level it is still necessary to confirm the homogeneity of the departments to provide support for the use of DEA in this context. The question to be asked here is how homogeneous the academic departments in the university really are. The departments work under a common mission statement but, as mentioned previously, interpretation of and emphasis on various aspects of this can differ. However the objectives were seen to be sufficiently congruent to allow a data envelopment analysis to be undertaken. As regards the similarity of market conditions, each department recruits its students and staff through the same procedure although it must be recognised that a Law degree has a significantly simpler task in attracting students than, say, a Mathematics course, and consequently can command higher grades for entry. This disparity does not undermine the usefulness of DEA however as the quality of students is taken into account in the value added variable.

A further condition for the selection of DMUs is the existence of suitable time periods over which measurement can take place. The preference here is for a natural time period and this requirement is met simply with the use of academic years in the analysis.

The application of DEA to academic departments in the University of Glamorgan produces a DMU set consisting of only twelve departments. This makes the use of window analysis desirable as the inclusion of an additional year of data effectively doubles the size of the DMU set. However, window analysis does bring complications as where financially based variables are used it becomes necessary to introduce an inflation scaling factor. Including data from more than one year can also be problematic if conditions are not sufficiently similar in all years of the analysis. For example, overall scholarly activity fell in the institution in 1990/91 but it is not possible to tell if any outside factors were involved in this or whether it is still fair to include both years results in the same analysis. Thus window analysis, in addition to obvious difficulties such as inflation scaling can produce some subtle difficulties of interpretation (unless the condition of ceteris paribus can be assumed to apply).

Variable Selection

Input Factors

1. Total Expenditure

Economic factors have been aggregated as, according to Thanassoulis, Dyson and Foster (1987) they represent the real resources available for management deployment. Also, where variables can be aggregated it gives greater scope for the inclusion of other factors. Inclusion of amounts relating to the department's relative use of library and technology facilities is important as it gives a truer indication of the real cost incurred by departments although the expenditure allocated to a department may not necessarily be the direct responsibility of the department head.

2. Room Space

This may not be as pertinent a variable in another setting or some other universities. Space at the University of Glamorgan is a major limiting factor on the activities of departments, hence the use of a measure of total m^2 space occupied by each department. A problem that may exist with this variable however, is that no account can be taken for the age and capacity of rooms and for how efficiently it is possible to use the space allocated to each department. Departments located in older, non-purpose built accommodation may be penalised.

Output Factors

1. Value Added

Value added is important as it gives a measure of students' performance and takes account of ability. If value added were not included, there would be no real indicator of the educational throughput of each department. There are a number of different value added methods which can be used. Of these, the comparative value added has been chosen instead of an Index method as it is less subjective and does not involve any arbitrary quantification of the difference between entry and exit grades. Nevertheless, there are still problems encountered in the value added methodology. These problems are mainly due to data availability but also involve difficulties in aggregation of different standards. The entry scores for each department are taken from records of students graduating in 1991. The scale used is A level points. However, not all students enter higher education with A levels. They may have national diplomas, Scottish Highers, Baccalaureates or no formal qualifications at all. In this study, the problem was overcome by assigning a basic A level score to all non-A level entry students, with this score derived from a basic minimum required for entry on to each particular course. With the 1991 graduates the non-standard entry was a small enough proportion to make this possible, although, with the increase of entry into higher education via access courses and qualifications such as GNVQs etc., the proportion of A level entrants may decrease to the point where this method does not remain appropriate. It would then become necessary to devise an alternative entry score for use in future analyses.

The same problem is less likely to occur with exit scores as they are made up of grade and credit points, the system to which the University has recently adjusted as part of a change to a modular structure of education. Ideally the individual grade points score would be available for each student via an information system whereas in this study, the data available related to grade bands such as 1st, 2:1 or pass, credit etc. These were then converted into a standard grade point level for each grade band which does not differentiate between a high or low 2:2, for example, although grade points allow this. The wastage rates for each department were included as part of the value added calculation although the wastage rates produced by the university do not adequately account for transfer between courses or accelerated study. A separate withdrawal rate variable could be used but this would compromise the discriminatory power of the model.

2. Research

The research output is extremely difficult to measure. Data availability is again a problem here with only simple total figures available for publications, conferences and higher degrees awarded. There is no differentiation between refereed and non-refereed papers or details on the size of publications. Thus an aggregation measure is used to provide an indicator of the level of scholarly activity in each department. This is not an ideal measure but this has to be considered in relation to the data available and the general lack of agreement on methods for the measurement of research.

3. Income Generated

The income generated variable is an aggregate measure also, including amounts relating to central WAB funding and consultancy income in addition to student's fees. The allocations are made in accordance with WAB weightings. It's possible however that these weightings may not necessarily reflect the true difference in costs of producing courses in various disciplines.

Model Formulation

The focus of the DEA in this study is on output oriented models. This choice is made because outputs, at department level, are more controllable by department heads than inputs and projections relating to target outputs are therefore more pertinent. Improvements in input usage are not ignored, however, as the results of input oriented models are also considered but not for purposes of comparisons with other techniques.

The constant returns to scale model is used in the bulk of the analysis. This is the most discriminating of the two possibilities but variable returns to scale results are also considered. For VRS to be used as the standard model there would need to be distinct evidence that variable returns to scale exist. If this is not the case then it is perfectly reasonable to project the results of an efficient department to the appropriate scale to envelope an inefficient DMU. Unfortunately, it is not always simple to determine whether variable returns exist as for variable returns to be evident in a correlation of scale and efficiency, a linear relationship between the two is required. Initial increasing then decreasing returns would not show in a correlation.

Sensitivity Analysis

An important part of the DEA methodology is the analysis of the sensitivity of the results to error and misspecification. The techniques employed for this are the removal of extremely efficient DMUs and the systematic removal of each variable in turn from the model. Substantial sensitivity to these checks undermines the viability of the application of DEA. Sensitivity to the first check could cast doubt on the usefulness of DEA as a measurement technique whilst sensitivity in the second is more context-specific. Conversely, a display of robustness would support the use of DEA.

There is a great deal of scope for more wide ranging checks on sensitivity. Different combinations of variables could be removed or alternative variables added to the model (subject to availability of data). Hypothetical DMUs could be used and their effect on the existing DMU set analysed. However, the techniques employed provide a good indication of the potential effect of variable misspecification and data error in the DEA results in this context.

6.2.2 Regression Methodology

Regression has been applied to the university with the same data set as for DEA. This does restrict the scope a little as it limits the opportunities for finding appropriate input/output relationships upon which to base measurement. The scope has been widened a little by the disaggregation of some financial variables.

The assumptions involved in regression put further limits on the inclusion of variables. The requirement for interval or ratio scaled data does not differ from DEA, but the assumption of linearity does. It is also necessary in regression to avoid multicollinearity (which occurs when independent variables are correlated) and to check for autocorrelation and homoscedasticity.

The analysis of regression results involves the interpretation of residuals. The method of interpretation adopted in this study is graphical. However, this particular method is only appropriate where there are, at most, two independent variables. If more are identified as contributing to the explanatory power of the model, a graph of the various residuals would be necessary. This would possibly occur if the technique were applied in another institution and would therefore require an alternative interpretation system and possibly the construction of a decision rule.

6.2.3 Financial Measures Methodology

The methods applied here were relatively simple, involving the interpretation and reallocation of institutional accounts. Some problems can occur with the lack of co-ordination between financial and academic years. The reallocation bases used were not always indisputable but were logically based. Much of the difficulty with the reallocation of central expenditure at departmental level is due to the absence of cost drivers. The direct cause of expenditure is difficult to identify. Hence costs were allocated using bases with which the costs were logically related. This unavoidably led to some arbitrariness.

The most difficult reallocation was that concerning the structural change within the Professional Studies faculty as this involved the analysis of staff movement and allocation of income and expenditure accordingly. Although following the staff movement was the clearest method of accounting for its effects, the reorganisation may still distort the results for purposes of comparison with departments in other faculties, particularly if any costs were involved in the reorganisation itself. Again, data availability is a restricting factor in the financial measures methodology.

6.2.4 Ratio Methods

This involved no separate calculations but only the analysis of existing ratios. This does still involve interpretation difficulties as a plethora of different figures are produced at varying levels of aggregation (course, department, faculty level etc.).

6.2.5 Comparisons

The numerical technique adopted for making comparisons is Kendalls Co-efficient of Concordance. This is necessary as with five different methods to compare, a bivariate correlation would be insufficient unless a correlation matrix were used, in which case interpretation difficulties arise. Kendalls co-efficient can be applied initially to all five methods and then with each method removed in turn. This shows if any method produces significantly different rankings to the others.

The methods applied in this study are wide-ranging and together involve overcoming a considerable number of obstacles, some context-specific, others more generic.

6.3 Evaluation Criteria

A number of criteria for evaluating performance indicators were identified by Cave Hanney and Kogan (1991). Of these criteria the following are to be used in the context of the University of Glamorgan study.

1. Manipulability

This refers to the potential for those being evaluated by a particular method to manipulate the results in their favour. An ability to influence the assessment results obviously undermines the reliability of any information produced by that technique.

2. Data Availability and Cost of Collection

This asks whether the appropriate data is readily available or whether the method in question will require any costly data collection. As the analysis is all based within a single institution, data collection difficulties and costs should be minimal regardless of which technique is used.

In addition to the above the following criteria are to applied in the evaluation.

1. Ease of Interpretation

The ease of interpretation refers to how easily the technique can be understood and whether it can be presented clearly and unambiguously. Application of this criteria involves analysis of the form that results take and what inferences can readily be drawn.

2. Comprehensiveness

The criteria of comprehensiveness is a consideration of what aspects of performance each technique measures, i.e. it is an evaluation of the broadness of each method. A comprehensive measure is one that can incorporate all relevant aspects of performance.

3. Sensitivity

The analysis of the sensitivity of the measurement techniques has a number of aspects. Firstly, the effect or potential effect of data error on the overall results. Secondly, the effect of possible misspecification of a measurement model. This aspect of sensitivity analysis only really applies to DEA and regression as the other methods are not open to a great deal of flexibility in their specification.

4. Timeliness

For information from performance to be of maximum benefit, it is necessary that it is received in time for any appropriate action to be taken or at least whilst the information is still pertinent. Most measurement techniques are likely to involve some time delay but it does vary according to the type of system used.

5. Complexity

This criteria examines the complexity which is inherent in the calculation of each measure.

6.4 Evaluation of Measurement Methods

6.4.1 Data Envelopment Analysis

Ease of Interpretation

The presentation of these results is an important issue. It is necessary for DEA results to be presented clearly as they are quite detailed and extensive. If a template is employed (as used in the results chapter), the results for inefficient departments are reasonably simply interpreted, but there is much subsidiary information that does require more expertise to understand.

In the results chapter the DEA results for 2Elecinf and 1Lawfina were examined in detail including analysis of the underlying data. Even for only two departments this required quite extensive explanation, although this may be partly due to the complexity of the calculation of the individual variables. The problem that ensues from a lack of understanding of the results produced is a potential mistrust and general lack of confidence in the said results. Hence when DEA is applied it is crucial that the results are presented clearly. A further issue in the interpretation of results is their potential ambiguity, i.e whether a high score is unambiguously good or bad. With DEA the efficiency score is very clear. A score of one represents relative efficiency and, for anything below, the lower the score the less efficient a department is. The overall interpretation is, however, less unambiguous, especially where slacks are involved. The efficiency score given is the reciprocal of the scaling factor of the most favourable of a department's variables. It is possible that large slacks could result in a DMU being reported as more efficient than it really is. There are a variety of efficiency scores that can be used including one which incorporates all slack and excess values but the use of these would compound any existing interpretation difficulties.

Manipulability

As DEA is a multi-variable technique there is no one single measure for a manager to focus on but individual variables could be influenced. DEA's system of weighting variables is intended to show DMUs in the "best possible light". This means, in effect, that a good performance in any one variable could be enough for a DMU to be reported as efficient. DEA's resistance to manipulation is therefore only as strong as the most vulnerable variable. Both the Income generated and total expenditure variables are not subject to manipulation as they are drawn from centrally prepared accounts. The room space variable may only be vulnerable in that it may be possible to use rooms for larger than usual class sizes. A trade-off exists between more efficient room use and good educational practice. However, DEA does not make this distinction, and favours minimisation of room use (or maximisation of output with stated room-use).

The research variable used has no qualitative element or any filtering mechanism for what cannot be included. As long as it is contained in the institutional bi-annual report it can be included.

The value added variable is vulnerable to any change in marking practices, so unscrupulous marking could distort this measure.

In summary, some of the DEA variables used are highly resistant to manipulation but others have identifiable weaknesses. As mentioned previously, the DEA method does focus on the most favourable variables for each department so care is needed to minimise the potential for manipulation.

Data Availability

The data for the variables are all currently available within the institution, although not in an ideal format. Much adjustment and reinterpretation is required to make the data suitable. The accounting data is not sufficiently departmentally based so some re-allocation is required for both income and expenditure figures. The value added data is drawn currently from numerous data bases, but the information produced is still incomplete. The research data is obtained from an institutional report produced biannually. The room allocation data is readily available though.

All of the data required to apply DEA is produced within the institution, but not naturally in a form suitable for analysis. Hence, the data that is used is what is currently available, not necessarily what would be used if a more advanced information system were in use.

Comprehensiveness

DEA measures whatever the model is configured to measure. There are a multitude of input and output variables that could be included (as interviews with department heads illustrated), should the DMU set be large enough to sustain it. DEA is not confined to measuring a single aspect of performance such as net expenditure, for example. It compares the inputs and outputs of each DMU with all other DMUs in the set and produces results reporting the relative performance of each in relation to a frontier of efficient DMUs and not to an average function.

The variables can be chosen to provide a sound measure of achievement of objectives with performance clearly linked to use of resources. Other factors having an influence on performance, although not necessarily within the control of department heads, can be included as environmental inputs.

DEA has the potential to be a very comprehensive performance measurement technique providing it is applied correctly and in a suitable context.

Sensitivity

The frontier methodology used in DEA means that only errors in DMUs on the frontier can affect any others, unless the effect of the error is to add or remove a DMU from the frontier. The effect of error and outliers on DEA is particularly severe as it is an extremal technique whereas methods such as regression are averaging models. Thus an error which affects the extremes can have serious repercussions throughout the analysis.

The initial sensitivity analysis for DEA was to remove efficient DMUs from the analysis. The three most efficient departments were removed one at a time. The effects of this were very wide ranging. No inefficient DMU remained unaffected with efficiency scores increasing in all cases. The most interesting result of the sensitivity analysis was what it revealed about how the characteristics of the efficient departments are projected into the results of inefficient departments. For example, removing 1Lawfina, a department strong in the rooms space variable and weak in Value added resulted in value added projections becoming more severe and room space projections less demanding. If an error had occurred in the calculation of just one of these variables for 1Lawfina alone, the potential effect on the entire DMU set would have been considerable. Similarly, all the enveloping departments have particular strengths and weaknesses which are projected in the same way and are subject to the same risks of error.

The second sensitivity analysis was to remove each variable in turn from the model. In all cases the correlation between the results from the reduced variable set and the full set were high, which would indicate that the overall results would not be too drastically affected by the omission of a variable or inclusion of a rogue element. The individual results may be more profoundly affected in some cases though. Removing a variable only has an affect on an individual DMU's results where that variable is one of the most favourable for a particular department. Where a variable is measuring a valuable aspect of performance not included in any other variable, the effect of its removal could be considerable for some departments. This was found to be the case in the University of Glamorgan study. It is difficult with DEA to tell which variable combination "fits" the data. It is not possible to tell which variable set is best, DEA being a deterministic model. In regression, if a variable is added, it is because it adds to the explanatory power of the model, i.e. it reduces statistical noise. With DEA, the concept of noise does not apply.

Timeliness

The DEA model applied to the university uses a wide range of data, much of which is only available a considerable time after the period to which it relates. All of the financial data were obtained from institutional accounts not available until some nine months after the accounting period has ended. The research information was obtained from biannual reports which could mean a delay of up to two years unless an alternative source was identified. The room space variable was available instantly though. Data for value added calculation also involved a delay as the student numbers and qualifications are only available several months after the period end. However, the practical difficulties involved with the University of Glamorgan application do not preclude the possibility of DEA producing vary timely results in a similar setting. If the technique were linked to an information system, the data would be available much quicker for all variables apart from the financial ones. Even the financial variables need not necessarily be drawn from institutional accounts but could be picked out of an on-line accounting system soon after the accounting period has ended. The timeliness of DEA results is therefore dependent on the sophistication of the information systems in the organisation in which the application is undertaken but the level of the information provided should be taken into account also. If one technique produces considerably more information than another, it could reasonably be expected to take longer.

Complexity

This is a highly complex technique and calculation of the results requires specific software, the capabilities of which are, as yet, limited. DEA cannot be graphically illustrated beyond three variables and the technique may be viewed as a type of "black box" by some managers. This lack of understanding could feasibly lead to its rejection by managers in favour of a more familiar and better understood technique. The DEA literature does not address the issues involved for managers to understand and accept it. There is also very little evidence in the literature of any ongoing applications of DEA. This lack of understanding and investigation may be a crucial limitation to practical managerial use of DEA.

6.4.2 Regression

Ease of Interpretation

Interpretation of regression results involves the analysis of residuals. This can be quite complex, particularly with a multivariate regression. Results can be presented graphically with up to two independent variables but beyond this only numerical analysis is possible. It is also unclear with regression as to what constitutes efficiency. There is no efficient frontier and a decision rule is needed to define efficiency as, say, one standard deviation above the regression line. The point at which efficiency is defined could be below the regression line, in which case a negative residual would not necessarily be inefficient. Such a rule could be arbitrarily decided.

The residuals do not provide a projection of an efficient output value but just show the difference between actual and predicted results. Simultaneous changes in input and output are not shown in regression as they are in DEA and the results that are produced by regression are not based on the observed performance of any other DMU.

Care in presentation is required, as with DEA, so as to avoid a potentially meaningless morass of numbers.

Manipulability

As the regression variables are constructed from the same data as the DEA variables, the opportunities for manipulation are very similar. The difference with regression is that the range of variables actually employed in the model is smaller and it is not sufficient to perform well in one input-output relationship as a negative residual may still be reported in remaining inputs. Regression is thus slightly more resilient to manipulation than DEA.

Data Availability

The same data availability problems apply for regression as for DEA as an identical data set was used for both.

Comprehensiveness

Regression, although capable of incorporating multiple input factors is confined to a single dependent variable, or output. This is a considerable drawback, especially in education where there are multiple outputs. Within these confines though, regression does have the capacity to be a reasonably comprehensive measure. Unfortunately, many variables that would ideally be included in a measurement model, may not fit the requirements for inclusion in a regression application. Thus, the model cannot always provide a sound measure of adherence to specified objectives.

The factors to be included must be shown to have a specific and significant relationship with the dependent variable. The performance of each department can then be compared to projections of this relationship. The aspect of performance measured is therefore confined to those variables that are shown to be part of this relationship.

Sensitivity

No separate sensitivity checks were undertaken for regression as it is an averaging and not a frontier method of measurement. Errors in data in a regression analysis will always very slightly affect all of the results as the regression line and hence the residuals will change. However, unless the error is considerable, the effect is likely to be negligible. The variables chosen for inclusion are done so by virtue of their inter-relationship and so removing variables that are shown to have explanatory power is going to assuredly affect the results, hence this sensitivity check was also felt to be unnecessary.

Timeliness

As the data used for the regression is very similar to the DEA data, the same conditions apply for producing timely results with regression as for DEA.

Complexity

Regression is also a quite complex technique but is fairly widely used and consequently better understood.

6.4.3 Ratio Methods

Ease of Interpretation

Although the FEMIS ratios are a fairly simple concept, the interpretation of the results can be quite complex. It involves the simultaneous consideration of a number of different ratios, although common practice is to focus primarily on the Staff-Student Ratio (SSR). It is necessary to consider the other ratios with the SSR to give it some context. The SSR itself is ambiguous. A high SSR may denote efficient teaching, but too high and it may be to the detriment of the educational process. The simplest way to present FEMIS results is in a table of ratios although it is still not easy to draw inferences from.

Manipulability

Staff-Student Ratios are vary vulnerable to manipulation. A head of department may aim for a high SSR at the expense of education quality with increased class sizes and reduced contact hours per student. This would result in a very favourable ratio (though not when considered with other FEMIS ratios as a whole).

Data Availability

The data for the FEMIS ratios is an integral part of the University's current information and evaluation system, hence there are no data availability problems with this method.

Comprehensiveness

The ratio methods provide a very simple measure which is not linked to any objectives and thus contains no measure of effectiveness. The principle ratio in the FEMIS system is the staff-student ratio. This is merely a measure of throughput and not very comprehensiveness. Although research activity may affect the FEMIS scores, it is not identified specifically. The SSR is a very narrow measure.

Sensitivity

The effects of data error with FEMIS ratios are largely dependent on where they occur. The calculation of the ratios is a quite complex process. If an error occurs in a figure for, say, total students, unless the error is large the effect is likely to be small. However, even a small error in a multiplying factor can have much more serious consequences. In practice, though, the FEMIS ratios are an established part of the university's information systems and errors in their calculation, whilst not impossible, are reasonably unlikely. The specification of the ratios are laid down by the Department for Education so there is little room for specification error.

Timeliness

The FEMIS ratios are part of an established information system and the results are thus available soon after the timetable and enrolment process is completed. This means that the ratios are available even whilst the academic year is in progress. No historic data or data relating to whole periods are used. The ratios are "snapshots" of the effective timetable.

Complexity

The results produced by the FEMIS system are fairly simple to understand but, although what it represents is a quite basic concept, the calculations themselves are quite complex. The procedure for these calculations has been clearly presented in a manual published by the Department for Education.

6.4.4 Financial Measures

Ease of Interpretation

These are relatively simple to interpret. A high figure for unit cost indicates an expensive discipline or an inefficient department (or both). With income and expenditure accounts the varying cost of different disciplines is already taken into account so the bottom line figure is an unambiguous measure of financial efficiency. The whole income and expenditure account is quite extensive but it is possible to present the results clearly in summary form. The financial measures are the simplest to present and interpret.

Manipulability

The main vulnerability here is the focus on cost saving at the expense of quality (although it is important to achieve both). Opportunities for manipulation of the figures are limited as, for the present study at least, the accounts are prepared centrally.

Data Availability

Financial data is obtained from institutional accounts, although the detail is somewhat sketchy. A more detailed set of financial data is available, however although not necessarily published for general use.

Comprehensiveness

As the name indicates the financial measures provide a report on the financial performance of each department only. The income and Expenditure account provides a net income or expenditure which takes into account the reallocation of all central expenditure and includes the Welsh Advisory Board funding allocations for each department. This does at least take into account the different costs associated with different disciplines and weights the income accordingly. The unit cost figures however, provide no indication of the different levels of income each department is responsible for generating and therefore shows technological departments in very bad light. Unit cost does not give an indication of any outputs at all. Income and Expenditure accounts can provide a measure of effectiveness if income maximisation is an objective but is still a very narrow measure to apply in an education context.

Sensitivity

Data errors in any financial measures calculations will affect only the results of those departments in whose accounts the errors occur. There are no multiplying factors to compound any errors. There is a small amount of sensitivity to the methods by which expenditure and income is allocated across departments. If a different basis was more appropriate the distribution of certain items would differ. Accounts are fairly rigourously prepared and checked however, so any fundamental errors are extremely unlikely.

Timeliness

These methods, as mentioned in the comment for DEA, are reliant on accounting data published some time after the year end. Once again, the length of the delay is largely dependent on the sophistication of the information systems.

Complexity

These are fairly simple with the only complexity involved being the reallocation of central expenditure. However, these allocations are made as logically as possible and do not involve any extensive calculations.

6.5 Quantitative Comparisons

Kendall's Coefficient of Concordance is a method which measures the overall agreement of a group of ranked variables. Kendall's Coefficient was applied to the rankings of the results from the five methods used in this study then again with each method excluded in turn. The results were as follows.

Methods Included	Coefficient of Concordance
All methods	0.5997
All except DEA	0.5673
All except Income & Expenditure Accounts	0.6133
All except Unit Cost	0.5648
All except FEMIS ratios	0.5526
All except Regression	0.8252

The results were fairly consistent except for when the regression results were excluded. The increase observed from the exclusion of regression indicates that the method is the least strongly linked with the others.

The overall agreement is fairly high indicating that there must be some common ground between the methods used (although less so with regression). However, for DEA to be of greater use than the other methods (and the hypothesis correct) it needs to be shown whether DEA produces a superior level of information.

6.6 Summary

This chapter has contained an evaluation of performance measurement methods. The initial stage was a review of the context of performance measurement in higher education and an introduction to the evaluation criteria employed. The application methodology was reviewed in the subsequent section and the problematic issues identified.

The bulk of this chapter contained a systematic review of DEA, regression, ratio and financial methods of measurement applying the criteria detailed in the first section. The final section was a quantitative comparison of the five methods. The following chapter contains the conclusions.

CONCLUSIONS

The early part of this thesis considered the theoretical difficulties of performance measurement in higher education, such as the problems of definition and measurement of output. The main thrust of this study, which focused on the application of a number of performance measurement techniques in the University of Glamorgan, confirmed that performance measurement in a University is indeed problematic. However, some measurement techniques do still have potential in this context.

The hypothesis of this study is that DEA provides more useful, detailed information than conventional methods of performance measurement in higher education.

The level of detail provided by DEA is considerable. It includes efficiency scores, projections for each variable and information on how those projections are obtained. The scope of measurement is only limited by DMU numbers (due to a need to restrict the degrees of freedom) and by the availability of quantifiable data. The availability of data can be a considerable constraint, the extent of which is dependent on the context of the application. If a sophisticated information system were in use in the institution where evaluation is being undertaken, data collection problems would be eased considerably. In the University of Glamorgan, with no such system as yet in use, the variable set was significantly limited by the data that were available and data collection was a time consuming process.

Regression analysis can draw from the same data as DEA but the variables included depend on how well they fit the data. Only those with explanatory power are included. FEMIS ratios are very narrow compared to DEA, measuring only staff and student numbers and the structure of teaching activity Income and Expenditure accounts and Unit cost data are restricted to financial activity. No effectiveness measure is included. Some measure of effectiveness can be built into the DEA model. In the University of Glamorgan, this measure was provided by the value added variable. This variable also took into account some measure of input quality. DEA is capable of including environmental input variables although in this study the only environmental inputs used were as part of the calculation of the value added output.

DEA is a practical method of defining efficiency. Inefficient DMUs are identified as demonstrably inefficient in comparison to a best practice frontier. This frontier, however, does cause problems for the integrity of the DEA results. The reliability of the information produced by DEA is undermined by its sensitivity. DEA is an extremal technique (i.e it is a frontier method). Any perturbation of this frontier caused by data error can significantly affect the results profiles. Regression is an averaging method. Mistakes in inputting or measuring data for regression analysis will be dissipated, hence the sensitivity of regression is much lower.

A significant strength of DEA is its objectivity in the assessment of the relative importance of each variable. Every DMU has the opportunity to be shown in the "best possible light". Regression, as a parametric technique, measures performance in comparison to a predetermined specification. DMUs have little scope within this to find a niche of efficiency as they do with DEA. Nevertheless, this flexibility does present difficulties for DEA. The flexible specification of the weighting system gives DMU managers the opportunity to focus on particular variables. Exceptional performance in a single variable is sufficient to attain efficiency, although other variables may be weak. Managers may concentrate on "easy" variables. This means that DEA is vulnerable to manipulation. However, it does also mean that inefficiency is more strongly defined.

DEA is a complex technique, and is less generally well understood than other methods, possibly partly due to lack of exposure. Regression is also quite complex but is a very well known technique. Implementation and interpretation of DEA requires some expertise. There is a danger with DEA of a "black box" effect. This ignorance of how DEA works is likely to lead to a lack of acceptance and understanding of the results it produces.

The information produced by DEA is extensive but can be presented in a digestible form. The inferences of the results are explicit with projections given for each variable and the basis of comparison identified. Results of regression can be difficult to interpret, as a decision rule is required for the definition of efficiency and residuals are then interpreted in accordance with that decision rule. Results of financial measures are clearly presented but interpretation may require some expertise. The FEMIS ratios are simple to interpret when each is considered in isolation but are difficult to use as a basis for drawing a complete picture.

In reference to the hypothesis, it has been shown that DEA does indeed provide more useful, detailed information than the other methods since, of the five techniques considered, DEA produces the most extensive and explicit description of the relative performance of each department. However, an unequivocal recommendation for the use of DEA is not possible as it has many caveats. DEA is extremely sensitive to error, open to manipulation and is very complicated. Nevertheless DEA does have the potential to be an extremely valuable technique as long as its limitations are recognised.

Certain areas of further research are necessary including investigation of the potential for ongoing application of DEA. This would include analysis of management responses and the feasibility of including DEA into a management information system. This sort of investigation could produce a clearer idea of how DEA actually works in practice and would enable more precise conclusions to be drawn on the applicability of DEA in both higher education and other contexts.

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APPENDIX A

MATHEMATICAL FORMULATION OF DATA ENVELOPMENT ANALYSIS

Objective:

$$\text{Maximise} \quad \frac{\sum_{r=1}^{s} UrYr,jo}{\sum_{i=1}^{m} ViXi,jo} . \qquad \text{(Efficiency Maximisation)}$$

Subject to the constraints:

$$\frac{\sum_{r=1}^{s} UrYrj}{\sum_{i=1}^{m} ViXij} <= 1 \qquad j = 1,...,jo...,N$$

(No DMU to have a score of greater than one with any weights assigned.)

$Ur > 0 \; ; \; r = 1...,S$
$Vi > 0 \; ; \; i = 1...,M$

(Positivity constraint)

Where
Yrj = observed amount of rth output for the jth DMU
Xij = observed amount of ith input for the jth DMU
jo = the DMU being assessed
(r = 1...,S; i = 1...,M; j = 1...,N)

APPENDIX B

VALUE ADDED CALCULATION

Notation

A = No. of students in department.
B = Mean Entry Score (per department)
C = No. of students completing per department (full-time)
D = No. of students completing per department (part-time)
E = No. of students enrolled in department(full-time)
F = No. of students enrolled in department(part-time)
G = Mean exit score (full-time, per department)
H = Mean exit score (part-time, per department)

The components of each departments' value added score are:-

1. Entry Score (as proportion of overall average) (1)
2. Expected Exit Score (2)
3. Actual Exit Score (3)

1. Entry Score (as proportion of average)

$$\frac{\text{Mean Entry per student in Department}}{\text{Overall Mean Student Entry Score}} = \frac{B}{\Sigma AB/\Sigma A}$$

$$= \frac{B\Sigma A}{\Sigma AB} = (1)$$

2. Expected Exit Score

$$(1) * \left(\begin{matrix}\text{Overall Mean}\\ \text{Exit Score per}\\ \text{F/T student}\end{matrix} * \begin{matrix}\text{No. F/T}\\ \text{Enrolments}\\ \text{in department}\end{matrix} + \begin{matrix}\text{Overall Mean}\\ \text{Exit Score per}\\ \text{P/T student}\end{matrix} * \begin{matrix}\text{No. P/T}\\ \text{Enrolments}\\ \text{in department}\end{matrix} \right) = (2)$$

Note:

$$\text{Overall Mean Exit Score per F/T student} = \frac{\text{Sum of completing F/T Students Exit Scores}}{\text{Sum of F/T Enrolments}}$$

$$= \frac{\Sigma GC}{\Sigma E}$$

Similarly:-

$$\text{Overall Mean Exit Score per P/T student} = \frac{\Sigma HD}{\Sigma F}$$

Therefore:-

$$\text{Expected Exit Score} = (F\Sigma HD/\Sigma F + E\Sigma GC/\Sigma E)*B\Sigma A/\Sigma AB \quad = \quad (2)$$

3. Actual Exit Score

$$\text{Actual Exit Score} = \text{Mean Exit Score * No. of students completing}$$

$$= GC + HD \qquad (3)$$

The value added score is the actual compared with the expected exit scores, i.e. (3)/(2)

$$= \frac{GC + HD}{(F\Sigma HD/\Sigma F + E\Sigma GC/\Sigma E)*B\Sigma A/\Sigma AB}$$

<u>Example Calculation</u>

Example Data

Dept	A	B	C	D	E	F	G	H	AB	GC	HD
X	30	10	27	3	30	5	850	750	300	22950	2250
Y	20	9	15	5	20	10	800	700	180	12000	3500
Z	20	9	15	5	15	5	800	700	180	12000	3500
	70		57	13	75	20			660	46950	9250

Calculation department X

1. Entry Score = $B\Sigma A/\Sigma AB$

   = 10*70/660 = 1.0606

2. Expected Exit Score = $(F\Sigma HD/\Sigma F + E\Sigma GC/\Sigma E)*B\Sigma A/\Sigma AB$

   = (5*9250/20 + 30*46950/75) * 1.0606

   = 22370.91643

3. Actual Exit Score = GC + HD

   = 22950 + 2250

   = 25200

Value Added per Student = 25200/22370.91643

   = 1.126

APPENDIX C

DEPARTMENT ABBREVIATIONS

BUSADMN	Department of Business and Administrative Studies
HUMANIT	Department of Humanities
LAWFINA	Department of Law and Finance
MANAGMT	Department of Management Studies
COMPUTR	Department of Computer Studies
ELECINF	Department of Electronics and Information Technology
MATHCOM	Department of Mathematics and Computing
MECHMAN	Department of Mechanical and Manufacturing Engineering
BEHCOMM	Department of Behavioural and Communication Studies
CIVBUIL	Department of Civil Engineering and Building
PROPDEV	Department of Property and Development Studies
SCICHEM	Department of Science and Chemical Engineering

Prefix:	1	1989/90
	2	1990/91

APPENDIX D

DEPARTMENTAL INCOME AND EXPENDITURE ACCOUNTS

Income and Expenditure 1989/90

	BUSINESS & ADMIN	HUMAN-ITIES	LAW & FINANCE	MANAGEMT
DIRECT INCOME	£	£	£	£
FEES: HOME	252609	263903	233096	39002
OVERSEAS	47062	4260	264290	17645
MISCELLANEOUS	0	75	2333	527
TOTAL DIRECT INCOME	299671	268238	499719	57174
ALLOCATED INCOME				
WAB ALLOCATION	1614341	770863	1077948	200576
MGCC TOP-UP	44034	21027	29403	5471
DEBT CHARGES	108463	106127	76219	54648
EARLY RETIREMENTS	33432	24629	30662	20870
TOTAL ALLOCATED INCOME	1800270	922645	1214232	281566
TOTAL INCOME	2099940	1190883	1713951	338740
PROFESSIONAL STUDS. REALLOCATION	236781	17958	82486	24664
REALLOCATED TOTAL INCOME	2336721	1208841	1796437	363404
DIRECT EXPENDITURE				
EMPLOYEES	542032	284077	313146	372298
STAFF RELATED EXP.	5493	8326	944	8700
PREMISES	0	0	0	0
TRANSPORT	6316	4235	2812	5039
SUPPLIES, SERVICES	34333	40337	50416	34644
TOTAL DIRECT EXP.	588173	336975	371318	420681
PROFESSIONAL STUDS. REALLOCATION	524674	349908	249165	181470
TOTAL REALLOCATED DIRECT EXPENDITURE	1112847	686883	620483	602151
TOTAL INCOME LESS DIRECT EXPENDITURE	1223875	521958	1175953	-238748

	LANGUAGE CENTRE	PREV BUSADMN	MGMT & LEGAL	ART & LANG
DIRECT INCOME	£	£	£	£
FEES: HOME	8992	252609	27859	0
OVERSEAS	0	47062	12604	24643
MISC.	0	0	377	156
TOTAL DIRECT INCOME	8992	299671	40840	24799
ALLOCATED INCOME				
WAB ALLOCATION	26266	-	-	-
MGCC TOP-UP	716	-	-	-
DEBT CHARGES	37087	-	-	-
EARLY RET'TS	10287	-	-	-
TOTAL ALLOCATED INCOME	74356	0	0	0
TOTAL INCOME	83348	299671	40840	24799
PROFESSIONAL STUDIES REALLOCATION	3421	-299671	-40840	-24799
REALLOCATED TOTAL INCOME	86769	0	0	0
DIRECT EXPENDITURE				
EMPLOYEES	127314	542032	265928	437888
STAFF RELATED EXP.	5527	5493	6214	5448
PREMISES	0	0	0	0
TRANSPORT	2089	6316	3599	2168
SUPPLS, SERVS, OTHER	33995	34333	24746	37702
TOTAL DIRECT EXP.	168925	588173	300487	483206
PROFESSIONAL STUDIES REALLOCATION	66649	-588173	-300487	-483206
TOTAL REALLOCATED DIRECT EXPENDITURE	235574	0	0	0
TOTAL INCOME LESS DIRECT EXPENDITURE	-148805	0	0	0

	COMPUTER STUDIES	ELEC & INF TECH	MATHS & COMPUTNG	MECH & MAN ENG
DIRECT INCOME	£	£	£	£
FEES: HOME	371617	243839	108057	149780
OVERSEAS	33594	147938	39830	255349
MISC.	160	307	0	1372
TOTAL DIRECT INCOME	405371	392084	147887	406501
ALLOCATED INCOME				
WAB ALLOCATION	1834489	1203712	533424	774390
MGCC TOP-UP	50039	32833	14550	21123
DEBT CHARGES	84707	196123	80535	248883
EARLY RET'TS	33729	27003	24530	21365
TOTAL ALLOCATED INCOME	2002963	1459671	653038	1065761
TOTAL INCOME	2408334	1851755	800925	1472262
PROFESSIONAL STUDIES REALLOCATION	-	-	-	-
REALLOCATED TOTAL INCOME	2408334	1851755	800925	1472262
DIRECT EXPENDITURE				
EMPLOYEES	757750	994367	575050	903331
STAFF RELATED EXP.	14931	25139	12120	20135
PREMISES	0	0	0	0
TRANSPORT	3826	8544	3152	6669
SUPPLS,SERVS,OTHER	90895	143264	47567	138055
TOTAL DIRECT EXP.	867402	1171314	637889	1068190
PROFESSIONAL STUDIES REALLOCATION	-	-	-	-
TOTAL REALLOCATED DIRECT EXPENDITURE	867402	1171314	637889	1068190
TOTAL INCOME LESS DIRECT EXPENDITURE	1540932	680441	163036	404072

	BEHAV'L & COMM'N	CIV ENG & BUILDG	PROPERTY & DEVPT
DIRECT INCOME	£	£	£
FEES: HOME	191376	321272	208631
OVERSEAS	14144	191232	54616
MISC.	180	2269	171
TOTAL DIRECT INCOME	205700	514773	263418
ALLOCATED INCOME			
WAB ALLOCATION	732304	1661035	981155
MGCC TOP-UP	19975	45307	26763
DEBT CHARGES	70742	376256	86319
EARLY RET'TS	27893	37883	18793
TOTAL ALLOCATED INCOME	850914	2120482	1113030
TOTAL INCOME	1056614	2635255	1376448
PROFESSIONAL STUDIES REALLOCATION	-	-	-
REALLOCATED TOTAL INCOME	1056614	2635255	1376448
DIRECT EXPENDITURE			
EMPLOYEES	658012	1132536	543453
STAFF RELATED EXP.	14106	27863	10225
PREMISES	316	227	0
TRANSPORT	11881	16904	5454
SUPPLS,SERVS,OTHER	81124	186091	55764
TOTAL DIRECT EXP.	765439	1363621	614896
PROFESSIONAL STUDIES REALLOCATION	-	-	-
TOTAL REALLOCATED DIRECT EXPENDITURE	765439	1363621	614896
TOTAL INCOME LESS DIRECT EXPENDITURE	291175	1271634	761552

	SCIENCE & CHEM ENG	TOTAL
DIRECT INCOME	£	£
FEES: HOME	309707	2982349
OVERSEAS	100572	1254840
MISC.	8130	16057
TOTAL DIRECT INCOME	418409	4253246
ALLOCATED INCOME		
WAB ALLOCATION	1456497	12867000
MGCC TOP-UP	39728	350968
DEBT CHARGES	341411	1867521
EARLY RET'TS	38971	350045
TOTAL ALLOCATED INCOME	1876607	15435533
TOTAL INCOME	2295016	19688779
PROFESSIONAL STUDIES REALLOCATION	-	0
REALLOCATED TOTAL INCOME	2295016	19688779
DIRECT EXPENDITURE		
EMPLOYEES	1328497	9777710
STAFF RELATED EXP.	13406	188070
PREMISES	96	639
TRANSPORT	12415	101419
SUPPLS, SERVS, OTHER	165027	1198292
TOTAL DIRECT EXP.	1519441	11266130
PROFESSIONAL STUDIES REALLOCATION	-	0
TOTAL REALLOCATED DIRECT EXPENDITURE	1519441	11266130
TOTAL INCOME LESS DIRECT EXPENDITURE	775575	8422649

ALLOCATED EXPENDITURE	BUSINESS & ADMIN	HUMAN- ITIES	LAW & FINANCE	MANAGEMT
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	33387	19769	30606	11446
FACULTIES TOTAL	33387	19769	30606	11446
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	23898	14150	21907	8193
ADMIN. DIV	54591	32323	50043	18715
REPROGRAPHICS	2111	1250	1935	724
PERSONNEL UNIT	6111	4502	5605	3815
PUBLICITY COMMITTEE	24543	14532	22498	8414
BUILDINGS OFFICER	81126	79378	57008	40874
CLEANING	21427	20966	15057	10796
SAFETY OFFICER	2250	1349	2062	804
PORTERS	11702	11450	8224	5896
REFECTORY	7631	4575	6996	2726
ADMINISTRATIVE AFFAIRS TOTAL	235390	184475	191336	100956
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPT	113376	64955	71575	81091
DIRECTORATE	12609	7224	7960	9019
CENTRAL ADMIN RECHARGES	18307	10488	11557	13093
EARLY RETIREMENTS	30059	17221	18977	21499
FINANCIAL AFFAIRS TOTAL	174351	99889	110069	124702
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT.	4636	3416	4252	2894
LRC, ITC, SPORT, HALL, STUD. SERVICES, DISABLED POLICY.	311303	184323	285369	106721
ACADEMIC AFFAIRS TOTAL	315939	187738	289622	109615
TOTAL ALLOCATIONS	759068	491871	621633	346720
TOTAL INCOME LESS TOTAL EXPENDITURE	464807	30087	554321	-585467

ALLOCATED EXPENDITURE	LANGUAGE CENTRE	PREV BUSADMN	MGMT & LEGAL	ART & LANG
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	7773	-	-	-
FACULTIES TOTAL	7773	-	-	-
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	5564	-	-	-
ADMIN DIV.	12709	-	-	-
REPROGRAPHICS	491	-	-	-
PERSONNEL UNIT	1880	-	-	-
PUBLICITY COMMITTEE	5714	-	-	-
BUILDINGS OFFICER	27740	-	-	-
CLEANING	7327	-	-	-
SAFETY OFFICER	532	-	-	-
PORTERS	4001	-	-	-
REFECTORY	1806	-	-	-
ADMINISTRATIVE AFFAIRS TOTAL	67765	-	-	-
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPARTMENT	32562	-	-	-
DIRECTORATE	3621	-	-	-
CENTRAL ADMIN RECHARGES	5258	-	-	-
EARLY RETIREMENTS FUNDING	8633	-	-	-
FINANCIAL AFFAIRS TOTAL	50074	-	-	-
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT.	1427	-	-	-
LRC,ITC,SPORT,HALL, STUDENT SERVICES, DISABLED POLICY.	72475	-	-	-
ACADEMIC AFFAIRS TOTAL	73901	-	-	-
TOTAL ALLOCATIONS	199513	-	-	-
TOTAL INCOME LESS TOTAL EXPENDITURE	-348318	-	-	-

ALLOCATED EXPENDITURE	COMPUTER STUDIES	ELEC & INF TECH	MATHS & COMPUTNG	MECH & MAN ENG
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	24921	17512	14579	11481
FACULTIES TOTAL	24921	17512	14579	11481
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	20811	14624	12175	9588
ADMIN DIV.	47538	33406	27810	21901
REPROGRAPHICS	1838	1292	1075	847
PERSONNEL UNIT	6165	4936	4484	3905
PUBLICITY COMMITTEE	21372	15019	12503	9846
BUILDINGS OFFICER	63357	146691	60236	186153
CLEANING	16734	38745	15910	49167
SAFETY OFFICER	1975	1399	1172	930
PORTERS	9139	21160	8689	26853
REFECTORY	6699	4746	3975	3155
ADMINISTRATIVE AFFAIRS TOTAL	195629	282017	148030	312345
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPARTMENT	167201	225783	122960	205904
DIRECTORATE	18596	25111	13675	22900
CENTRAL ADMIN RECHARGES	26997	36456	19854	33247
EARLY RETIREMENTS FUNDING	44329	59861	32600	54591
FINANCIAL AFFAIRS TOTAL	257123	347211	189089	316642
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT.	4678	3745	3402	2963
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	271083	190495	158588	124890
ACADEMIC AFFAIRS TOTAL	275761	194240	161990	127852
TOTAL ALLOCATIONS	753434	840981	513688	768321
TOTAL INCOME LESS TOTAL EXPENDITURE	787498	-160540	-350652	-364249

ALLOCATED EXPENDITURE	BEHAV'L & COMM'N	CIV ENG & BUILDG	PROPERTY & DEVPT
ALLOCATION FROM FACULTIES:	£	£	£
FACULTY OFFICE	19390	23377	13532
FACULTIES TOTAL	19390	23377	13532
ALLOCATION FROM ADMIN. AFFAIRS:			
ACADEMIC DIV.	16038	19336	11193
ADMIN DIV.	36635	44168	25567
REPROGRAPHICS	1417	1708	989
PERSONNEL UNIT	5098	6924	3435
PUBLICITY COMMITTEE	16471	19857	11494
BUILDINGS OFFICER	52912	281423	64563
CLEANING	13975	74330	17053
SAFETY OFFICER	1529	1858	1065
PORTERS	7633	40596	9313
REFECTORY	5185	6301	3611
ADMINISTRATIVE AFFAIRS TOTAL	156892	496501	148282
ALLOCATION FROM FINANCIAL AFFAIRS:			
FINANCE DEPARTMENT	147546	262852	118527
DIRECTORATE	16410	29234	13182
CENTRAL ADMIN RECHARGES	23824	42442	19138
EARLY RETIREMENTS FUNDING	39119	69689	31425
FINANCIAL AFFAIRS TOTAL	226898	404217	182273
ALLOCATION FROM ACADEMIC AFFAIRS:			
STAFF DEVELOPMENT.	3868	5254	2606
LRC,ITC,SPORT,HALL, STUDENT SERVICES, DISABLED POLICY.	208912	251870	145796
ACADEMIC AFFAIRS TOTAL	212781	257123	148402
TOTAL ALLOCATIONS	615961	1181219	492489
TOTAL INCOME LESS TOTAL EXPENDITURE	-324787	90415	269063

ALLOCATED EXPENDITURE	SCIENCE & CHEM ENG	TOTAL
ALLOCATION FROM FACULTIES:	£	£
FACULTY OFFICE	22444	250219
FACULTIES TOTAL	22444	250219
ALLOCATION FROM ADMIN. AFFAIRS:		
ACADEMIC DIV.	18564	196040
ADMIN DIV.	42405	447812
REPROGRAPHICS	1640	17315
PERSONNEL UNIT	7123	63982
PUBLICITY COMMITTEE	19065	201328
BUILDINGS OFFICER	255360	1396823
CLEANING	67446	368933
SAFETY OFFICER	1792	18717
PORTERS	36836	201493
REFECTORY	6080	63486
ADMINISTRATIVE AFFAIRS TOTAL	456311	2975929
ALLOCATION FROM FINANCIAL AFFAIRS:		
FINANCE DEPARTMENT	292888	1907220
DIRECTORATE	32574	212116
CENTRAL ADMIN RECHARGES	47292	307953
EARLY RETIREMENTS FUNDING	77653	505656
FINANCIAL AFFAIRS TOTAL	450406	2932945
ALLOCATION FROM ACADEMIC AFFAIRS:		
STAFF DEVELOPMENT.	5405	48546
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	241815	2553640
ACADEMIC AFFAIRS TOTAL	247219	2602186
TOTAL ALLOCATIONS	1176381	8761279
TOTAL INCOME LESS TOTAL EXPENDITURE	-400806	-338630

<u>Income and Expenditure 1990/91</u>

	BUSINESS & ADMIN	HUMAN-ITIES	LAW & FINANCE	MANAGEMT
DIRECT INCOME	£	£	£	£
FEES: HOME	856832	504535	446310	129328
OVERSEAS	43704	4563	440464	13038
MISC.	2571	1590	2142	6684
TOTAL DIRECT INCOME	903107	510688	888916	149050
ALLOCATED INCOME				
WAB ALLOCATION	1795974	859786	935494	271080
MGCC TOP-UP	55644	26638	28984	8399
DEBT CHARGES	117435	114905	82524	59169
EARLY RET'TS	37890	23301	38194	18033
TOTAL ALLOCATED INCOME	2006942	1024631	1085195	356680
TOTAL INCOME	2910049	1535319	1974111	505730
DIRECT EXPENDITURE				
EMPLOYEES	978181	578935	867158	501968
STAFF RELATED EXP.	7306	769	5914	6348
PREMISES	0	0	0	0
TRANSPORT	13053	1496	15369	9236
SUPPLS, SERVS, OTHER	41278	41805	47016	29803
TOTAL DIRECT EXPENDITURE	1039818	623005	935457	547355
TOTAL INCOME LESS DIRECT EXPENDITURE	1870231	912314	1038654	-41625

	LANGUAGE CENTRE	COMPUTER STUDIES	ELEC & INF TECH	MATHS & COMPUTNG
DIRECT INCOME	£	£	£	£
FEES: HOME	4968	553954	349861	155171
OVERSEAS	0	25329	99397	11640
MISC.	1422	-47	854	1072
TOTAL DIRECT INCOME	6390	579236	450112	167883
ALLOCATED INCOME				
WAB ALLOCATION	8466	1595363	1007584	446886
MGCC TOP-UP	262	49428	31217	13846
DEBT CHARGES	40155	91714	212346	87196
EARLY RET'TS	15703	39713	33635	23706
TOTAL ALLOCATED INCOME	64586	1776219	1284783	571634
TOTAL INCOME	70976	2355455	1734895	739517
DIRECT EXPENDITURE				
EMPLOYEES	275915	1034468	1052700	684578
STAFF RELATED EXP.	98	6174	20434	5466
PREMISES	5	830	454	11
TRANSPORT	83	6644	12236	2734
SUPPLS, SERVS, OTHER	3174	79814	109182	52490
TOTAL DIRECT EXPENDITURE	279275	1127930	1195006	745279
TOTAL INCOME LESS DIRECT EXPENDITURE	-208299	1227525	539889	-5762

	MECH & MAN ENG	BEHAV'L & COMM'N	CIV ENG & BUILDG	PROPERTY & DEVPT
DIRECT INCOME	£	£	£	£
FEES: HOME	189376	327695	535225	331450
OVERSEAS	179176	4563	149324	26621
MISC.	105	1016	3166	1034
TOTAL DIRECT INCOME	368657	333274	687715	359105
ALLOCATED INCOME				
WAB ALLOCATION	571212	731544	1614391	909375
MGCC TOP-UP	17698	22665	50018	28175
DEBT CHARGES	269470	76594	407380	93460
EARLY RET'TS	20363	28569	40220	19451
TOTAL ALLOCATED INCOME	878743	859372	2112009	1050461
TOTAL INCOME	1247400	1192646	2799724	1409566
DIRECT EXPENDITURE				
EMPLOYEES	844815	744412	1240141	553920
STAFF RELATED EXP.	1928	262	10169	2421
PREMISES	0	1109	2674	4926
TRANSPORT	8636	6095	10049	4609
SUPPLS,SERVS,OTHER	69603	57340	105316	56168
TOTAL DIRECT EXPENDITURE	924982	809218	1368349	622044
TOTAL INCOME LESS DIRECT EXPENDITURE	322418	383428	1431375	787522

	SCIENCE & CHEM ENG	TOTAL
DIRECT INCOME	£	£
FEES: HOME	553226	4937931
OVERSEAS	108112	1105931
MISC.	678	22287
TOTAL DIRECT INCOME	662016	6066149
ALLOCATED INCOME		
WAB ALLOCATION	1517846	12265000
MGCC TOP-UP	47027	380000
DEBT CHARGES	369652	2022000
EARLY RET'TS	40220	379000
TOTAL ALLOCATED INCOME	1974744	15046000
TOTAL INCOME	2636760	21112149
DIRECT EXPENDITURE		
EMPLOYEES	1432179	10789370
STAFF RELATED EXP.	5828	73117
PREMISES	-18	9991
TRANSPORT	12567	102807
SUPPLS,SERVS,OTHER	115683	808672
TOTAL DIRECT EXPENDITURE	1566239	11783957
TOTAL INCOME LESS DIRECT EXPENDITURE	1070521	9328192

ALLOCATED EXPENDITURE	BUSINESS & ADMIN	HUMAN-ITIES	LAW & FINANCE	MANAGEMT
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	29589	15482	24702	9786
CONTINUING EDUC'N	10495	5491	8762	3471
FACULTIES TOTAL	40084	20973	33464	13257
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	32794	17158	27377	10846
ADMIN DIV.	60556	31684	50555	20027
REPROGRAPHICS	471	246	393	156
PERSONNEL UNIT	16359	10061	16491	7786
PUBLICITY COMMITTEE	27543	14411	22994	9109
BUILDINGS OFFICER	92411	90420	64939	46560
CLEANING	20865	20416	14662	10513
SAFETY OFFICER	1940	1024	1636	656
PORTERS	13556	13264	9526	6830
REFECTORY	14770	7794	12455	4989
ADMINISTRATIVE AFFAIRS TOTAL	281264	206477	221028	117471
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPARTMENT	209072	125265	188088	110054
DIRECTORATE	32126	19248	28902	16911
CENTRAL ADMIN RECHARGES	17924	10739	16125	9435
EARLY RETIREMENTS FUNDING	35283	21140	31742	18573
FINANCIAL AFFAIRS TOTAL	294405	176392	264857	154973
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT	2364	1454	2383	1125
LEATGS	1555	956	1568	740
PLAYGROUP	10460	5520	8821	3534
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	329768	172542	275305	109062
ACADEMIC AFFAIRS TOTAL	344147	180471	288077	114461
TOTAL ALLOCATIONS	959900	584313	807426	400162
TOTAL INCOME LESS TOTAL EXPENDITURE	910331	328000	231228	-441787

ALLOCATED EXPENDITURE	LANGUAGE CENTRE	COMPUTER STUDIES	ELEC & INF TECH	MATHS & COMPUTNG
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	6379	32946	22254	18510
CONTINUING EDUC'N	2263	7638	5160	4291
FACULTIES TOTAL	8641	40584	27414	22801
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	7070	23867	16122	13409
ADMIN DIV.	13055	44073	29770	24761
REPROGRAPHICS	102	343	232	193
PERSONNEL UNIT	6780	17147	14522	10236
PUBLICITY COMMITTEE	5938	20046	13541	11262
BUILDINGS OFFICER	31598	72171	167097	68615
CLEANING	7134	16295	37728	15492
SAFETY OFFICER	437	1443	992	814
PORTERS	4635	10587	24511	10065
REFECTORY	3328	10981	7547	6196
ADMINISTRATIVE AFFAIRS TOTAL	80076	216952	312061	161044
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPARTMENT	56153	226788	240275	149850
DIRECTORATE	8628	34848	36920	23026
CENTRAL ADMIN RECHARGES	4814	19443	20599	12847
EARLY RETIREMENTS FUNDING	9476	38273	40549	25289
FINANCIAL AFFAIRS TOTAL	79071	319352	338343	211012
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT	980	2477	2098	1479
LEATGS	645	1630	1381	973
PLAYGROUP	2357	7777	5345	4388
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	71092	240009	162120	134843
ACADEMIC AFFAIRS TOTAL	75073	251893	170944	141683
TOTAL ALLOCATIONS	242862	828781	848762	536540
TOTAL INCOME LESS TOTAL EXPENDITURE	-451160	398745	-308873	-542302

ALLOCATED EXPENDITURE	MECH & MAN ENG	BEHAV'L & COMM'N	CIV ENG & BUILDG	PROPERTY & DEVPT
ALLOCATION FROM FACULTIES:	£	£	£	£
FACULTY OFFICE	17446	25213	28998	16206
CONTINUING EDUC'N	4045	6261	7201	4025
FACULTIES TOTAL	21491	31474	36200	20231
ALLOCATION FROM ADMIN. AFFAIRS:				
ACADEMIC DIV.	12639	19564	22502	12576
ADMIN DIV.	23339	36127	41552	23222
REPROGRAPHICS	181	281	323	181
PERSONNEL UNIT	8792	12335	17365	8398
PUBLICITY COMMITTEE	10615	16432	18899	10562
BUILDINGS OFFICER	212048	60272	320571	73544
CLEANING	47877	13609	72380	16605
SAFETY OFFICER	762	1173	1367	756
PORTERS	31105	8841	47024	10788
REFECTORY	5802	8925	10405	5758
ADMINISTRATIVE AFFAIRS TOTAL	353162	177559	552390	162391
ALLOCATION FROM FINANCIAL AFFAIRS:				
FINANCE DEPARTMENT	185982	162706	275128	125072
DIRECTORATE	28578	25001	42276	19218
CENTRAL ADMIN RECHARGES	15945	13949	23588	10723
EARLY RETIREMENTS FUNDING	31386	27458	46430	21107
FINANCIAL AFFAIRS TOTAL	261891	229115	387422	176120
ALLOCATION FROM ACADEMIC AFFAIRS:				
STAFF DEVELOPMENT	1270	1782	2509	1213
LEATGS	836	1173	1651	798
PLAYGROUP	4109	6321	7369	4078
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	127095	196737	226280	126461
ACADEMIC AFFAIRS TOTAL	133311	206013	237809	132551
TOTAL ALLOCATIONS	769855	644161	1213821	491293
TOTAL INCOME LESS TOTAL EXPENDITURE	-447436	-260733	217555	296229

ALLOCATED EXPENDITURE	SCIENCE & CHEM ENG	TOTAL
ALLOCATION FROM FACULTIES:	£	£
FACULTY OFFICE	28395	275906
CONTINUING EDUC'N	7052	76155
FACULTIES TOTAL	35446	352061
ALLOCATION FROM ADMIN. AFFAIRS:		
ACADEMIC DIV.	22034	237958
ADMIN DIV.	40687	439407
REPROGRAPHICS	316	3417
PERSONNEL UNIT	17365	163638
PUBLICITY COMMITTEE	18506	199858
BUILDINGS OFFICER	290882	1591128
CLEANING	65677	359254
SAFETY OFFICER	1341	14341
PORTERS	42669	233402
REFECTORY	10205	109154
ADMINISTRATIVE AFFAIRS TOTAL	509682	3351557
ALLOCATION FROM FINANCIAL AFFAIRS:		
FINANCE DEPARTMENT	314917	2369350
DIRECTORATE	48390	364073
CENTRAL ADMIN RECHARGES	26999	203131
EARLY RETIREMENTS FUNDING	53145	399849
FINANCIAL AFFAIRS TOTAL	443451	3336403
ALLOCATION FROM ACADEMIC AFFAIRS:		
STAFF DEVELOPMENT	2509	23642
LEATGS	1651	15557
PLAYGROUP	7227	77306
LRC, ITC, SPORT, HALL, STUDENT SERVICES, DISABLED POLICY.	221567	2392881
ACADEMIC AFFAIRS TOTAL	232954	2509386
TOTAL ALLOCATIONS	1221533	9549407
TOTAL INCOME LESS TOTAL EXPENDITURE	-151012	-221215

APPENDIX E

DEA DATA

Output Data

Department	Income Generated (£)	Scholarly Activity	Total Value Added
2BUSADMN	2700321.00	22.33	875.13
2HUMANIT	1371068.00	33.33	368.86
2LAWFINA	1825055.00	27.00	439.79
2MANAGMT	420316.80	18.00	222.14
2COMPUTR	2175701.00	26.33	522.14
2ELECINF	1458392.00	17.67	415.46
2MATHCOM	615077.30	9.67	315.02
2MECHMAN	940263.60	19.00	513.02
2BEHCOMM	1065322.00	36.00	303.13
2CIVBUIL	2303221.00	15.67	550.68
2PROPDEV	1269108.00	19.33	201.43
2SCICHEM	2180910.00	22.33	638.37
1BUSADMN	2332278.00	21.67	770.71
1HUMANIT	1146204.00	42.33	348.10
1LAWFINA	1799866.00	37.67	418.79
1MANAGMT	306219.50	10.00	182.86
1COMPUTR	2429201.00	38.00	555.52
1ELECINF	1730464.00	38.00	426.71
1MATHCOM	738849.50	19.00	337.32
1MECHMAN	1280288.00	24.67	467.73
1BEHCOMM	1017216.00	32.67	301.33
1CIVBUIL	2359467.00	20.67	566.48
1PROPDEV	1349694.00	37.33	214.36
1SCICHEM	2033221.00	37.67	604.66

Input Data

Department	Total Expenditure (£)	Room Space m^2
2BUSADMN	1274918.00	1197.50
2HUMANIT	790794.30	1171.80
2LAWFINA	1076157.00	841.58
2MANAGMT	580505.30	603.40
2COMPUTR	1426520.00	935.30
2ELECINF	1367758.00	2165.50
2MATHCOM	894953.70	889.23
2MECHMAN	992426.60	2748.05
2BEHCOMM	937196.70	781.10
2CIVBUIL	1432603.00	4154.45
2PROPDEV	681424.30	953.10
2SCICHEM	1775862.00	3769.70
1BUSADMN	1468897.00	1197.50
1HUMANIT	908335.00	1171.80
1LAWFINA	815779.00	841.58
1MANAGMT	684359.70	603.40
1COMPUTR	1327191.00	935.30
1ELECINF	1480306.00	2165.50
1MATHCOM	892470.30	889.23
1MECHMAN	1228277.00	2748.05
1BEHCOMM	957063.60	781.10
1CIVBUIL	1539538.00	4154.45
1PROPDEV	725731.90	953.10
1SCICHEM	1879705.00	3769.70

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