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ESTIMATION OF ACADEMIC LABOR SERVICES

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A MULTIPLE OUTPUT TRANSLOG COST FUNCTION ESTIMATION OF ACADEMIC LABOR SERVICES

By

William Dale King

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ABSTRACT

A MULTIPLE OUTPUT TRANSLOG COST FUNCTION ESTIMATION OF ACADEMIC LABOR SERVICES

By

William Dale King

This study addresses several questions concerning the structure of costs in higher education using a multiple output model. The objectives are: 1) to analyze the demand for academic labor services consisting of tenured faculty, non-tenured faculty, and graduate assistants, 2) to analyze the supply of outputs of higher education consisting of undergraduate instruction, graduate instruction, and research, and 3) to test for the existance of separability, homogeneity of outputs, constant returns to scale, and a Cobb-Douglas structure to costs in higher education.

These objectives require estimation of production relations without placing a priori constraints on the elasticities of substitution among the academic labor services and the outputs. Thus, a translog cost function is specified as a quadratic approximation to the production process. It is from these estimates of this cost function that the appropriate elasticities of demand, marginal cost, and substitution are derived. In addition, a system of direct demand equations for the academic labor services is also solved simultaneously to provide results to compare with the translog cost function.

Estimation is based on the underlying assumption that

technology is similar across all departments included at Michigan State University and leads to the following conclusions. Among the academic labor services, all are substitutes in production. The non-tenured faculty and graduate assistants are the easiest substitutes. The tenured faculty and non-tenured faculty are less substitutable with the tenured faculty and graduate assistants having the least substitutability. The elasticities of demand for the inputs are all negative and sufficiently small to indicate all are inelastic in demand.

Estimates of the elasticity of substitution for the outputs indicate all are easy substitutes. The easiest substitution is between undergraduate instruction and research. Research and graduate instruction are less substitutable with graduate and undergraduate instruction having the least substitutability. In addition, increasing returns to scale exist for all outputs with research and undergraduate instruction having the greatest returns and graduate instruction having the least.

Finally, the evidence did not suggest that any constraints on the translog cost function are appropriate. The tests of separability, homogeneity of outputs, constant returns to scale, and a Cobb-Douglas form produced results that were significantly different from the unrestricted translog model. The direct demand model was found to contain symmetry in the cross-price elasticities and homogeneity of the outputs.

To my wife, Nancy, and my family

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"I must candidly admit that I do not know what the elasticity of supply of resources to the educational sector is or how easy it is to switch resources in the educational sector from teaching to research (at least at the margin where the switch counts). The substitutability of resources within the sector depends on the production function for the various outputs produced by the sector."

(Nerlove, 1972)

CHAPTER I

INTRODUCTION

Regardless of how optimistically one would like to view the future, there is little doubt that enrollments in higher education will decline sharply over the next decade. The cost of not knowing the substitutability of resources will continue to rise as administrators and faculty try to restructure their institutions to meet these changing circumstances.

Empirical estimates of the elasticities of substitution among the faculty and graduate assistants, for example, are important in determining the impact upon a university when reduced enrollments necessitate cutbacks in the teaching staff. Administrators have many options available. They could adopt programs to promote early retirement for the tenured faculty, lengthen the time period necessary for faculty members to gain tenure, or eliminate graduate assistantships in specific programs. Currently, very little is known about how each of these employment policies will affect the overall teaching and research aspects of a university. It may be true that many provosts, deans, or department chairpersons have some intuitive notion of how their institutions can adapt to the declines of the future, but it is doubtful that anyone has a clear grasp of the system of higher education as a whole (Nerlove, 1972).

There are several ways one might go about modeling the structure of higher education. Each approach implies a different assumption about the process being examined. There are two that are relevant to the study presented here. The first approach assumes that an instructional department at one university is faced with the same production function as similar departments at other universities. The other approach assumes that although each department within a university may face a slightly different production function, the differences are not great enough to overshadow the valuable information that can be provided to the central administration of the university. The latter approach is the direction taken by this study. This is not to say that one is absolutely preferable to the other, but that both can provide a unique perspective on a rather complicated production process.

It appears to be reasonable, based on the above assumptions, to build a model that makes use of data relating to a particular discipline across many universities. Obviously, the generating of student credit hours for an Economics Department is more closely related to the production process at other Economics Departments than it is to, say, the production process applicable to the science or agriculture departments within that university. This relationship would exist for most disciplines of higher education. Research facilities, laboratory equipment, and the size of lectures, all vary widely from department to department or college to college within a university. However appealing the cross-university approach may be, there are two serious problems that arise when building a model on this basis. The first problem is that it is extremely difficult to gather all of the data necessary for the model. Most universities compile data on student credit hours and the number of tenured faculty. This data could be collected with only minimal difficulty. On the other hand, research output and full-time equivalent employment for temporary faculty are not collected at most universities, thus requiring rough approximations and guesswork on the part of the model builder. Second, there would be some question as to whether the data were completely consistent and compiled according to a uniform set of definitions across all universities. This would be especially true for measuring research output and graduate student credit hours. At this point, this approach for modeling higher education would be inordinately expensive if one were to collect enough data that would be suitable for analysis.

The use of data within one university and across disciplines also deserves careful examination. The problems with the above approach do not exist when the data are collected from a carefully defined set of reports at one university. Michigan State University collects all of the necessary data required to make this analysis feasible. The data are compiled according to one uniform set of definitions and can be considered reliable for the years being studied. These reports are all available in several forms from the Office of Institutional Research. Using this approach requires that we assume that all disciplines and departments within the university are facing the same production function. This assumption is, indeed, very strong since we do not know, and are unable to test, the extent to which it is true. Violating this assumption will affect the estimates of the model in two important ways. First, it can contribute significantly to the inability of the model to satisfy the first- and second-order conditions necessary for a cost function to be well behaved. Not satisfying the first- and second-order conditions would lead us to believe that the departments of the university are not making decisions based on cost minimization. However, this can be an erroneous conclusion because it does not rule out the possibility that the departments are truly cost minimizers but acting according to a different production function. Thus, we could reject the model for not properly estimating the cost function when, in fact, there may be more than one. The second difficulty arises in the estimates of elasticities presented in a later chapter. In the one instance where the estimated cost function is well-behaved, approximately one-half of the coefficients are not significantly different from zero. This implies that the elasticity estimates using these coefficients may not be reliable.

Obviously, it would strengthen the analysis considerably if the model could account for the differences in the structure of production across departments. It is unfortunate that this cannot be done and we must suggest this as a direction for future investigation. Since the purpose of this study is to provide the central administration with university-wide policy proposals, it is necessary to assume only one production function exists for all of the departments within the university. The differences applicable to any one department from the single (hypothetical) production function being created here will appear in the error term of the specific regression equations. The role of the error term will be two-fold in this study. It will contain the information on the distance certain departments are from their production frontiers and will also be a measure of the inadequacy of specifying an entire university's output with one production function.

The Nature of Academic Labor Services

It is necessary, for the purposes of comparison, to state explicitly what we regard as an intuitive understanding of the workings of the university and the process of providing instruction and research. The outputs we include in our model are undergraduate teaching, graduate teaching, and research by department. The inputs we measure are three types of academic labor services defined as the number of full-time equivalent tenured faculty, non-tenured faculty including tenure stream and temporary faculty,[1] and graduate assistants by department. We believe the non-tenured and tenured faculty to be substitutes in all three outputs of undergraduate instruction, graduate instruction, and research. The non-tenured faculty are at the beginning of their academic careers and therefore may be more interested in scholarly publication and graduate instruction but, nevertheless, the tenured and non-tenured faculty share departmental responsibilities for producing all of the outputs. The difference between these two labor services is only in the degree that they are substitutes.

Graduate assistants, on the other hand, play a different role in the production process because they are both inputs and outputs. It becomes important here to separate the three outputs and discuss each one separately. In undergraduate teaching, we feel the graduate assistants are fairly good substitutes for both types of faculty. There are two reasons for this. The first is that graduate assistants frequently act as instructors for classes without requiring supervision by any faculty member. Second, if student demand for freshman and sophomore classes increases rapidly, class sizes can be increased and more graduate assistants may be hired to assist the faculty member teaching the class. Rather than hiring a temporary faculty member to

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[1] Less than 10 percent of the departments in the university have temporary faculty that are more than 25 percent of the total number of non-tenured faculty.

maintain the same class size with more sections taught, most departments may, instead, hire more graduate assistants with larger classes. Thus, although the graduate assistants are working under the supervision of a faculty member and might be considered to be a complement to the faculty, they are actually substitutes.

With respect to research, we believe graduate assistants are complements to both types of faculty. This is because they produce very little research separate from the faculty. Further, we feel that the faculty can attract graduate assistants to provide much of the "leg work" of their research activity, although the data are not available to prove this. It is for this reason that the graduate assistants would be expected to be complements with the faculty.

We believe graduate assistants do not make any significant contribution to graduate instruction. Although there might be some support by graduate assistants to the faculty, we do not know its size. Therefore, we will assume it to be negligible, and expect to find that graduate assistants are only slight substitutes with both types of faculty with respect to graduate teaching. However, this does not mean that a correlation does not exist between the size of a graduate program and the number of graduate assistantships offered by the department. In fact, the number of graduate students taught by departments was found to be a significant predictor of the number of graduate assistants employed.[2] There is an additional connection between the graduate program and the number of graduate assistants. The salary paid graduate assistants not only reimburses them for services performed, but also represents a stipend for their enrollment in the graduate program. There is not sufficient data available to determine how graduate assistants divide their working hours between assisting faculty members and providing unsupervised undergraduate instruction. This makes it difficult to determine whether the substitutability between graduate assistants and the faculty in undergraduate and graduate instruction overshadows the complementarity in research. We will assume that it does. This is because we believe the percentage of all of the graduate assistants' time spent on instruction is greater than that spent on research. Again, these relationships reflect a tentative *a priori* understanding of the structure of academic labor services in higher education and will be used in the analysis to provide a basis for comparing the estimates of the model presented in Chapter IV.

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[2] In the demand equations, to be discussed in Chapter IV, we discovered that graduate student credit hours was a significant variable in predicting the number of graduate assistant appointments. It is estimated from direct demand equations that a 10% increase in graduate instruction will cause approximately a 3% increase in graduate assistant employment (See Table 4.3).

Two Analytical Approaches

There are two analytical approaches to the study of higher education presented in this study. The first method of analysis is through a system of demand equations with each equation representing the demand for each input. The second method is a multiple output cost function estimation where the substitutability of the inputs can be examined in a joint production framework. This will produce not only demand elasticities for the inputs but, also, elasticities of substitution and the supply elasticities of the outputs.

This study concentrates only on what are referred to as "academic labor services" or those individuals employed in instructional departments and holding faculty rank or a graduate assistant appointment. This seemingly narrow approach is justified on practical grounds. First, the costs related to the operation of a college or university that are not devoted to faculty or graduate assistant salaries are extremely difficult to associate with any one department. Many different departments share the same facilities such as classrooms, laboratories, and libraries. In addition, a major goal of academic administrators (provosts, deans, and chairpersons) is to optimize the mix of their academic labor services with all other expenditures assumed to be of secondary importance.

Within the examination of higher education at the departmental level this study's objectives are: 1) to test the applicability of *a priori* restrictions of homogeneity, separability, and a Cobb-Douglas form, 2) to estimate the demand elasticities and cross-price elasticities of academic labor services, 3) to estimate the supply elasticities of outputs. These objectives, once achieved, can assist in the discussion of changing the structure or composition of academic labor services in higher education consisting of tenured faculty, non-tenured faculty, and graduate assistants. The outputs will consist of undergraduate instruction, graduate instruction, and research.

Chapter II provides the theoretical framework on which the direct demand analysis and joint cost function analyses are based. Both analyses are developed with their necessary assumptions and testable restrictions. The methods of estimation and determination of elasticities derived are also presented in this chapter.

In Chapter III, special attention is paid to how the inputs and outputs of higher education are specified. This chapter also elaborates upon many of the problems that must be overcome in order to make it possible to adapt the available data to a model of the academic labor services of higher education.

Chapter IV provides the actual estimates from the system of demand equations and the translog cost function. The various elasticities are presented along with the applicability of the translog cost function and the restrictions of homogeneity of the outputs, separability, and the joint product Cobb-Douglas functional form.

It is possible to apply the various elasticities derived from both methods to answer specific policy questions. Some of these questions will be formulated and answered in Chapter V. The issues that can be addressed relate to the decline of undergraduate enrollments, continuation of certain graduate programs, and projecting the impact of salary increases on the employment of labor services.

Chapter VI summarizes the conclusions and draws the relevant policy implications toward higher education based on the findings of the models. The findings indicate that it would be appropriate for a university in times of decline, to reduce its non-tenured faculty level first, with graduate assistants supporting their teaching loads and the tenured faculty providing the research.

CHAPTER II

THEORETICAL FRAMEWORK

Introduction

The structure of higher education can be studied from two rather different perspectives. The first, which will be referred to as the "Direct Demand Analysis," looks at the structure as a system of simultaneous demand equations for each factor input. The second perspective, termed the "Joint Product Cost Function," considers the underlying cost function directly and from it the demand equations for the factor inputs are derived.

The interpretation of the demand for academic labor services will be based on these two perspectives. Both methods are included in this study because each contains advantages and disadvantages. The direct demand analysis provides a simple, straightforward approach unencumbered by long mathematical expressions or abstract functional designs. It is less attractive because it does not allow us to derive the elasticities of substitution of the factor inputs or provide an insight into the jointness of outputs. These are serious disadvantages since it is the existence of the jointness of the outputs that makes the study of higher education an interesting economic and econometric problem and the motivation for this research. The direct demand analysis is nonetheless important to this study for two reasons. First, it does provide estimates of demand elasticities and scale economies that are useful for comparison with the estimates derived from the joint product cost function; and, second, it provides some measure of how well higher education conforms to the principles of microeconomic theory.

The joint product cost function, on the other hand, easily produces the elasticities of substitution, demand, and marginal cost but also contains disadvantages in the empirical estimation of the model. In this model, there are 27 independent variables. The large number of coefficients to be estimated increases the likelihood that many coefficients will be insignificant. Since the elasticities of substitution, demand, and marginal cost are estimated from insignificant coefficients, the major disadvantage with this approach is the unreliable estimates of these coefficients.

The Approach to the Specification of Joint Production

The process of producing higher education can be examined through the estimation of either a production function or cost function. Estimating a production function requires specifying the inputs in terms of quantities while a cost function uses inputs prices. The general production function of the model is:

$$f(Y_1, Y_2, \ldots, Y_m, X_1, X_2, \ldots, X_n) = 0 \qquad (2.1)$$

where the Y's represent the outputs and the X's represent the inputs (Hall, 1973; Brown et al., 1979).

Applying this general form to our higher education problem we have:

$$f(Y_U, Y_G, Y_R, L_T, L_N, L_A, K, E, M) = 0 \tag{2.2}$$

where Y_U, Y_G, Y_R are the outputs of undergraduate and graduate education and research respectively. The academic labor services are defined as tenured faculty (L_T), non-tenured faculty (L_N), and graduate assistance (L_A). The other inputs relate to capital (K), other employment (E), and materials, supplies and services (M). Since this study is only concerned with the substitution among the types of academic labor services, all of the other inputs can be expressed as elements within the subset X_i.[1]

Typically, this general function is developed further to gain more insight into the specific relationships under study. Hudson and Jorgensen (1974), Griffin (1977), Fuss (1977), and Brown et al. (1979), are popular examples of models making use of an aggregator function.

Applying the use of aggregator functions to higher education, we can create a production function that permits us to examine only the outputs and the academic labor services. Writing the general functional form in a form that will permit us to examine only the outputs and the academic

---

[1] This is consistent with the terminology developed in Hasenkamp (1976).

labor services, we have:

$$f(h(Y_U, Y_G, Y_R, L_T, L_N, L_A),\ k(X, \ldots X_e)) = 0 \qquad (2.3)$$

where functions h and k, are referred to as aggregators.

Writing the production function in this form implies the existence of weak separability between the outputs and academic labor inputs, $h(\cdot)$, and the non-academic inputs, $k(\cdot)$.

Weak separability means that the marginal rates of substitution between elements within an aggregator are independent of the quantities demanded of elements outside the aggregator. For example, the cost-minimizing choice of the academic labor mix is independent of either the mix or level of capital, other employment, or materials (Berndt and Christensen, 1973).

Imposing separability provides two important results. First, only under the existence of separability do aggregate functions exist. Second, the existence of aggregates which are homothetic in their components implies an underlying two-stage optimization procedure: optimize the mix of components <u>within</u> each aggregate and then optimize the mix of the aggregates.

It is important that we assume separability exists in order to reduce our model from <u>all</u> of the inputs and outputs of higher education to only those inputs (and outputs) that we feel are important to the decision-making processes. The constraint of separability does agree, generally, with what we find in how employment decisions are made. Additionally, the separability constraint justifies the separate construction of a sub-model into only the academic labor and output components expressed as:

$$f(h(Y_U, Y_G, Y_R, L_T, L_N, L_A)) = 0 \qquad (2.4)$$

and is the structural basis for this study (Fuss, 1977).

The translog function used in this study is assumed to be a good second-order approximation to an unknown function and not the "exact" function (Fuss, 1977).[2] More recently, Brown et al. (1979), were able to test the constraint of separability between multiple inputs and multiple outputs. Their test will be incorporated into this study. However, the existence of separability between any non-academic labor input and the outputs can only be assumed and cannot be proven due to the non-labor inputs being excluded from the sub-model (and not included in the data).

In this section we establish the specific direct demand equations from the general functional form developed above. In addition, the model is also modified to the existence of the constraints of homogeneity, symmetry, and constant returns to scale. Having derived the general functional form as stated in equation (2.4) above, the relevant demand equations are a transformation of this form. Demand for each

---

[2] Denny and Fuss (1977) present a comprehensive discussion of an exact versus an approximate production function.

type of academic labor service is a function not only of the price of that input but also the price of the other labor inputs and the outputs:

$$
\begin{aligned}
L_T &= L_T(P_T, P_N, P_A, Y_U, Y_G, Y_R) \\
L_N &= L_N(P_T, P_N, P_A, Y_U, Y_G, Y_R) \qquad (2.5) \\
L_A &= L_A(P_T, P_N, P_A, Y_U, Y_G, Y_R)
\end{aligned}
$$

where P_T, P_N, and P_A represent the full-time equivalent salaries of the tenured faculty, non-tenured faculty, and graduate assistants respectively.

Expressing all of the variables as logarithms, the unrestricted model has the input quantities as the dependent variable with the dependent variables consisting of the input prices and the output quantities.

The explicit equations to be estimated in the Unrestricted Direct Demand model are:

$$
\begin{aligned}
\ell nL_T &= A_1 + B_1 \ell nP_T + B_2 \ell nP_N + B_3 \ell nP_A + C_1 \ell nY_U + C_2 \ell nY_G + C_3 \ell nY_R + e_1 \\
\ell nL_N &= A_2 + B_4 \ell nP_T + B_5 \ell nP_N + B_6 \ell nP_A + C_4 \ell nY_U + C_5 \ell nY_G + C_6 \ell nY_R + e_2 \qquad (2.6) \\
\ell nL_A &= A_3 + B_7 \ell nP_T + B_8 \ell nP_N + B_9 \ell nP_A + C_7 \ell nY_U + C_8 \ell nY_G + C_9 \ell nY_R + e_3
\end{aligned}
$$

where the ℓnL's are the logarithms of the quantities of the inputs of tenured faculty (T), non-tenured faculty (N), and graduate assistants (A); and the ℓnP's are the logarithms of the prices of inputs T, N, and A. The outputs (Y's) are defined as undergraduate student credit hours (U), graduate student credit hours (G), and research (R). The coefficients denoted by B's or C's represent the elasticities of the prices and outputs, respectively.

The constraints of homogeneity of input prices, symmetry of cross price elasticities, and constant returns to scale are all possible conditions that can be imposed. Linear homogeneity of a production function implies that when the quantities of all the inputs employed are increased by some proportion, say doubled, then output will also be doubled. Given that linear homogeneity exists in a production process, then it can be said the model is homogeneous of degree zero with respect to input price. That is to say -- the relative quantities or quantity ratios of the factor inputs used in the production process are determined solely by relative prices (or price ratios). If all input prices were to double, there would be no change in the relative quantities of the inputs employed. This condition can be represented by setting the sum of the coefficients on prices equal to zero in each equation which will place three restrictions on the model.

The demand equations, with the constraint of homogeneity, become:

$$
\begin{aligned}
\ell nL_T &= A_1' + B_1'\ell n(P_T/P_A) + B_2'\ell n(P_N/P_A) + C_1'\ell nY_U + C_2'\ell nY_G + C_3'\ell nY_R + e_1' \\
\ell nL_N &= A_2' + B_4'\ell n(P_T/P_A) + B_5'\ell n(P_N/P_A) + C_4'\ell nY_U + C_5'\ell nY_G + C_6'\ell nY_R + e_2' \quad (2.7) \\
\ell nL_A &= A_3' + B_7'\ell n(P_T/P_A) + B_8'\ell n(P_N/P_A) + C_7'\ell nY_U + C_8'\ell nY_G + C_9'\ell nY_R + e_3'
\end{aligned}
$$

The remaining parameters are determined from the linear homogeneity constraint:

$$B_3' = -(B_1' + B_2')$$
$$B_6' = -(B_4' + B_5') \qquad (2.8)$$
$$B_9' = -(B_7' + B_8')$$

Constant returns to scale can be imposed by setting the sum of the coefficients on the outputs equal to one. This can be done easily, with exactly the same procedure used for the homogeneity constraint, and will result in a total of six restrictions. When we impose constant returns to scale, the model becomes:

$$\ell nL_T = A_1'' + B_1''\ell n(P_T/P_A) + B_2''\ell n(P_N/P_A) + C_1''\ell n(Y_U/Y_R) + C_2''\ell n(Y_G/Y_R) + e_1''$$
$$\ell nL_N = A_2'' + B_4''\ell n(P_T/P_A) + B_5''\ell n(P_N/P_A) + C_4''\ell n(Y_U/Y_R) + C_5''\ell n(Y_G/Y_R) + e_2'' \qquad (2.9)$$
$$\ell nL_A = A_3'' + B_7''\ell n(P_T/P_A) + B_8''\ell n(P_N/P_A) + C_7''\ell n(Y_U/Y_R) + C_8''\ell n(Y_G/Y_R) + e_3''$$

The coefficients B_i are determined in the same manner as before, and the coefficients C_j are found with the following equations:

$$C_3'' = 1 - (C_1'' + C_2'')$$
$$C_6'' = 1 - (C_4'' + C_5'') \qquad (2.10)$$
$$C_9'' = 1 - (C_7'' + C_8'')$$

The final constraint that can be placed on the direct demand model is symmetry of the cross price elasticities. This can be defined as:

$$\frac{\partial \ell nL_i}{\partial \ell nP_j} = \frac{\partial \ell nL_j}{\partial \ell nP_i} \qquad (2.11)$$

This implies a reciprocal relationship of the corresponding coefficients on "other prices" in the demand equations. For example, the coefficient on P_A in the demand equation L_T must be equal to the coefficient P_T in the demand equation L_A. This will place three restrictions on the model stated as:

$$
\begin{aligned}
\ell nL_T &= A_1''' + B_1'''\ell nP_T + B_2'''\ell nP_N + B_3'''\ell nP_A + C_1'''\ell nY_U + C_2'''\ell nY_G + C_3'''\ell nY_R + e_1''' \\
\ell nL_N &= A_2''' + B_2'''\ell nP_T + B_5'''\ell nP_N + B_6'''\ell nP_A + C_4'''\ell nY_U + C_5'''\ell nY_G + C_6'''\ell nY_R + e_2''' \\
\ell nL_A &= A_3''' + B_3'''\ell nP_T + B_6'''\ell nP_N + B_9'''\ell nP_A + C_7'''\ell nY_U + C_8'''\ell nY_G + C_9'''\ell nY_R + e_3'''
\end{aligned}
\tag{2.12}
$$

The combination of symmetry and homogeneity will place six restrictions on the model. The Direct Demand equations to be estimated become:

$$
\begin{aligned}
\ell nL_T &= A_1^* + B_1^*\ell n(P_T/P_A) + B_2^*\ell n(P_N/P_A) + C_1^*\ell nY_U + C_2^*\ell nY_G + C_3^*\ell nY_R + e_1^* \\
\ell nL_N &= A_2^* + B_2^*\ell n(P_T/P_A) + B_4^*\ell n(P_N/P_A) + C_4^*\ell nY_U + C_5^*\ell nY_G + C_6^*\ell nY_R + e_2^* \\
\ell nL_A &= A_3^* + C_7^*\ell nY_U + C_8^*\ell nY_G + C_9^*\ell nY_R + e_3^*
\end{aligned}
\tag{2.13}
$$

with the remaining parameters determined from the following equations:

$$
\begin{aligned}
B_3^* &= -(B_1^* + B_2^*) \\
B_6^* &= -(B_2^* + B_4^*) \\
B_9^* &= B_1^* + B_4^* + 2B_2^*
\end{aligned}
\tag{2.14}
$$

In conclusion, these four restrictive models will be tested against the unrestricted model to determine the most appropriate set of constraints to represent the production process of higher education.

The Joint Product Cost Function -- The General Form

As stated by Christensen and Green (1976), recent application of duality theory to problems in economics has resulted in many useful results for the study of production and cost relationship. (An extensive review of the literature is contained in Diewert (1974).) A fundamental result is that, given certain regularity conditions to be stated later, for every production function there is a cost function that is dual to it. Thus, the structure of production can be studied empirically through the use of either a production function or a cost function.

It is commonly accepted in the literature that the choice between a cost function or production function should be made on the economic characteristics of the market to be analyzed. It is thought that if prices are exogenous, a cost function is the best approach; and, if prices are endogenous, a production function model is preferable (Grant, 1979). Berndt and Wood (1975) suggest that, "At the level of an individual firm it may be reasonable to assume that the supply of inputs is perfectly elastic and, therefore, the input prices are fixed." It is for this reason that we have chosen to estimate a joint cost function with the assumption of exogenous prices. However, there is an economic issue regarding whether factor prices are truly exogenous even when a production function is estimated. If the factor prices are endogenous, or $P = P(Y)$, then even under constant returns to scale, the cost function is $C(Y,P) = C(Y,P(Y))$ and not

$C(Y,P) = Y \times C(P)$ as is commonly assumed. The consequence of assuming that factor prices are not exogenous and therefore not constant to the firm is that an underlying supply curve for each factor must be specified. In practice, this is not usually done. Most models make use of production function estimates that were derived through the first-order conditions in Cobb-Douglas and CES functions or factor share equations as in translog estimation. Thus, the data points represent points where the price ratio equals the marginal rate of transformation. The price ratio, in turn, requires prices to be determined outside the model and must be exogenous. Therefore, the point to be expressed here is that, regardless of whether a cost or production function is explicitly used in the study, both make use of exogenous prices if first-order conditions or share equations are used.

It has been shown by Hall (1973) that for every joint production function (similar to equation 2.4 above) there exists a joint cost function that is dual to it. We can, therefore, write our model in terms of a unique joint cost function as:

$$C = g(w(Y_U, Y_G, Y_R), y(P_T, P_N, P_A)) \qquad (2.15)$$

Proving this transformation requires the use of the Shephard-Uzawa-McFadden-Duality Theorem for Joint Cost Functions. Briefly, this theorem states that, if it is assumed that the transformation function $f(Y,X)$ has a strictly convex input structure (to rule out perfect substitutes or perfect complements), then there exists a unique joint cost function that is dual to the transformation function. Further, the cost function must be positive, linear, homogeneous, nondecreasing, and concave in factor prices. Finally, the cost function must obey Shephard's lemma, which states that the vector of cost minimizing factor inputs is equal to the vector of derivatives of the cost function with respect to factor prices. (A proof of this theorem exists in McFadden (1973)).

As stated in the introduction, this study will illustrate how the translog function proposed by Christensen et al. (1973) can be used to represent a joint cost function. The translog is a second-order approximation to a general functional form. It will permit the testing of assumptions on the structure of cost in higher education such as the separability between the input and the outputs and the homogeneity of outputs along with determining the Allen-Uzawa Elasticities of Substitution (Berndt & Christensen, 1973a and Denny and Fuss, 1977). The translog form places no *a priori* restrictions on the substitution possibilities among the inputs.

The general form of the translog cost function is as follows:

$$\ell nC = A_o + \sum_{i=1}^{m} A_i \ell nY_i + \sum_{j=1}^{n} B_j \ell nP_j$$
$$+ \tfrac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{n} D_{ij} \ell nY_i \ell nY_j$$
$$+ \tfrac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{n} G_{ij} \ell nP_i \ell nP_j \qquad (2.16)$$
$$+ \sum_{i=1}^{m} \sum_{j=1}^{n} R_{ij} \ell nY_i \ell nP_j$$

where A_o represent the state of technological knowledge, A_i, B_j, D_{ij}, G_{ij}, and R_{ij} are the technologically determined cost parameters of the first-and second-order parameters. Additionally, the $D_{ij} = D_{ji}$ and the $G_{ij} = G_{ji}$ but the $R_{ij} \neq R_{ji}$ are imposed as a symmetry condition (for further discussion see Berndt and Christensen, 1973b). The expression in (2.16) has one neutral parameter (A_o), n + m first-order parameters (A_i,B_j), and (m+1)(m/2) + (n+1)(n/2) + mn second-order parameters where m is the number of outputs and n is the number of inputs.

The application of the assumption of homogeneity of input prices as described by Brown (1979) for the multiproduct cost function implies:

$$\sum_{j=1}^{m} B_j = 1 \qquad \sum_{i=1}^{n} G_{ij} = 0 \qquad \sum_{i=1}^{n} R_{ij} = 0 \qquad (2.17)$$

The derivation of these restrictions is contained in Christensen et al. (1973). They imply that as input prices rise by a fixed percentage, total cost will rise by that same percentage. The second-order terms are forced to sum to zero in order to negate any effect they might have on total cost. This will leave the B_j to exert the only impact on total cost as input prices change and maintain the economic meaning of homogeneity. This assumption, along with the condition of symmetry, reduces the number of free parameters to $(m+n+1)(m+n)/2$.

Relating the general format to the specific cost function under study, we can thus modify the unrestricted case of the translog cost function for higher education to include the constraints of symmetry and homogeneity in input prices with perfectly competitive factor markets.

The joint cost function of academic labor services contains a total of 34 independent parameters. There are one neutral, 6 first-order, and 27 second-order parameters to be determined. The symmetry condition eliminates 6 parameters while the homogeneity of input prices permits the number of free parameters to be reduced by an additional 7. Thus, the number of free parameters to be estimated in the model is 21.

The Joint Product Cost Function -- Share Equations

In order to estimate the parameters of (2.16) above, we can employ the simple method of ordinary least squares. However, additional information is available, which will result in improved efficiency of estimation. Shephard's lemma assures us that there is a set of factor demand equations which can be derived from the joint cost function. In logarithmic form, Shephard's lemma can be written:

$$\frac{\partial \ell n C}{\partial \ell n P_j} = \frac{\partial C}{\partial P_j} \cdot \frac{P_j}{C} = \frac{P_j X_j}{C} = S_j$$

where S_j is the share of input j in total cost. For the joint translog function in (2.16), this yields the following three equations representing the input shares of each of the factors:

$$S_T = B_T + \sum_{i=1}^{n} G_{iT} \ell n P_i + \sum_{j=1}^{m} R_{jT} \ell n Y_j$$

$$S_N = B_N + \sum_{i=1}^{n} G_{iN} \ell n P_i + \sum_{j=1}^{m} R_{jN} \ell n Y_j \qquad (2.18)$$

$$S_A = B_A + \sum_{i=1}^{n} G_{iA} \ell n P_i + \sum_{j=1}^{m} R_{jA} \ell n Y_j$$

(where i = T,N,A, and j = U,G,R)

Additionally, we can improve the efficiency of the estimates of the model by using the information contained in the outputs (Hall, 1973 and Burgess, 1974). However, in order to take advantage of this information we must first add an additional assumption to the model. We must assume that perfect competition also exists in the output market. It is difficult to imagine instruction and research among the departments of a university as having a homogeneous product. An argument can be made that this condition is not appropriate since instruction or research in business and engineering, for example, is a far different product than that being offered in music or history. However, we must accept these difficulties in the output market in order to gain the needed efficiency in the model. Thus, we can define the output shares as being equal to the percentage change in total cost that occurs with a percentage change in an output produced or:

$$\frac{\partial \ell nC}{\partial \ell nY_i} = \frac{\partial C}{\partial Y_i} \cdot \frac{Y_i}{C} = \frac{P_i Y_i}{C} = M_i \tag{2.19}$$

where M_i is the share of output i of total cost. This produces the following three additional equations:

$$M_U = A_U + \sum_{j=1}^{m} D_{jU} \ell nY_j + \sum_{i=1}^{n} R_{Ui} \ell nP_i$$

$$M_G = A_G + \sum_{j=1}^{m} D_{jG} \ell nY_j + \sum_{i=1}^{n} R_{Gi} \ell nP_i \tag{2.20}$$

$$M_R = A_R + \sum_{j=1}^{m} D_{jR} \ell nY_j + \sum_{i=1}^{n} R_{Ri} \ell nP_i$$

(where j = U,G,R and i = T,N,A)

These applications of Shephard's lemma and perfect competition produce six equations in addition to the joint cost function without the addition of any unknown parameters. By specifying that the seven equations have joint normal additive disturbances, the method of maximum likelihood can be used to estimate the unknown parameters. Although the cost function could be estimated in isolation from the cost share equations, it is clearly more efficient to estimate the parameters with the six share equations included in the system. Actually, only four equations can be used in the regression model since one equation of both the output and input shares is linearly dependent on the other two.

The Joint Product Cost Function -- First- and Second-Order Conditions

As previously stated, the translog is a second-order approximation to a general functional form. It is necessary for this approximation to meet several regularity conditions for us to maintain the belief that it is a reasonable representation of the true (and unknown) cost function of a university's academic labor services. First, each fitted input share and output share must be greater than zero and less than one at every data point. A model that predicts inputs (and outputs) that contribute negatively or greater than 100 percent to total cost (total revenue) is without meaning. Second, it is necessary for a function to have a strictly convex input structure as stated in the Duality Theorem above. Following the procedure employed by Grant (1979), from Allen (1938), we can test the convexity conditions by computing determinants of the bordered Hessian matrix.

$$H = \begin{bmatrix} 0 & \cdots & H_i & \cdots & H_n \\ \vdots & \ddots & & H_{ij} & \vdots \\ H_i & & H_{ii} & & \vdots \\ \vdots & H_{ij} & & \ddots & \vdots \\ H_n & \cdots & \cdots & \cdots & H_{nn} \end{bmatrix} \tag{2.21}$$

where $H_i = M_i$, $H_{ii} = \sigma_{ii}$, and $H_{ij} = \sigma_{ij}$

It then remains to demonstrate that the determinants of this matrix are negative semi-definite at each data point. The translog specification of the partial A-UES has no a priori constraints. Rather, the elasticities are allowed to vary with the share equations. In the instances where these first- and second-order conditions are met, the relevant elasticities will be assumed to reflect accurately the structure of the academic labor costs in higher education.

The Joint Product Cost Function -- The Constraints

This section is designed to identify the specific form of the joint product cost function including the constraints of: i) homogeneity of output prices, ii) separability, iii) constant returns to scale, iv) homogeneity and separability, and v) the Cobb-Douglas form.

Separability between the inputs and outputs implies that the transformation function can be written with an aggregator function to represent output as a single variable. It is assumed the transformation function can be written as:

$$f(Y_U, Y_G, Y_R) = g(L_T, L_N, L_A) \qquad (2.22)$$

The dual cost function to (2.22) above would be:

$$c = k(h^*(Y_U, Y_G, Y_R), g^*(P_T, P_N, P_A)) \qquad (2.23)$$

The restrictiveness of separability illustrated by (2.23) implies that the relative marginal costs for any two outputs are independent of input prices (Brown, 1979). Thus, the existence of separable input and output functions states that the specific mix of outputs produced is not affected by the mix of inputs used and vice versa. (Despite this restrictiveness, the separable form of the transformation function was commonly accepted in empirical studies as recently as Hasenkamp's (1976) treatise.) The test of the separability of the outputs can be incorporated into the model with the addition of the constraint that the ratio of marginal costs of any two outputs will not be affected by a change in the price of any factor input. For the translog form this implies that:

$$\frac{\partial[(A_i + \sum_{j=1}^{m} D_{ij}\ell nY_j + \sum_{i=1}^{n} R_{ij}\ell nP_i)/A_k + \sum_{j=1}^{m} D_{kj}\ell nY_j + \sum_{i=1}^{n} R_{ki}\ell nP_i)]}{\partial \ell nP_\ell} = 0 \qquad (2.24)$$

This rather complicated partial derivative is equivalent to setting the $R_{ij} = 0$ for all i's and j's in the cost function. Since there are m(n-1) free R_{ij}, equation (2.24) places six additional restrictions on the previously unrestricted model.[3]

Another important step in this analysis is to test whether, given a fixed percentage increase in all of the outputs, total costs rise by that percentage. This constraint

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[3] Except for linear homogeneity of input prices.

is known as the homogeneity of outputs. We can incorporate it into the model with the following equalities:

$$\sum_{i=1}^{m} D_{ij} = 0 \quad \text{and} \quad \sum_{i=1}^{m} R_{ij} = 0 \tag{2.25}$$

where i = U, G, and R; k = U, G, and R; and j = T, N, and A. These conditions have the effect of isolating the impact of all increases on total cost to be solely determined by coefficients on the first-order parameters, namely A_U, A_G, A_R. This assumption will place five additional restrictions on the unrestricted model. Only two of the conditions in $\sum_{j=1}^{m} R_{ij} = 0$ are independent since $\sum_{i=1}^{n} R_{ij} = 0$ has already been imposed by the assumption of linear homogeneity in factor prices (Brown et al., 1979). In addition, by further assuming the $\sum_{j=1}^{m} A_j = 1$, the cost function can be tested for constant returns to scale.

The last constraint useful in this analysis is equivalent to transforming the generalized translog function into a Cobb-Douglas multiple output cost function. Conveniently, the translog cost function reduces to a Cobb-Douglas cost function by setting all second-order parameters equal to zero. Stated algebraically:

$$D_{ij} = 0,\ G_{ij} = 0, \text{ and } R_{ij} = 0 \text{ for all i and j.} \tag{2.26}$$

These constraints cause the cost function to be reduced to only six non-zero terms, which are the intercept, the three output terms, and the two input price terms. (The third input price was previously dropped with the homogeneity of prices constraint which forced the $\sum_{i=1}^{n} B_i = 1$). It is thus an even more restrictive case than the combined constraints of output homogeneity and separability.

In summary, there are five constraints that can be imposed on the unrestricted model. First, homogeneity in the outputs assumes total cost will change by the same percentage as the outputs. Second, separability assumes the general transformation function can be written with an aggregator function for the outputs and inputs separately. Third, homogeneity and separability can be imposed together. Fourth, the model can be constrained to include constant returns to scale. Fifth, the model can be constrained to represent a Cobb-Douglas multiple output function.

The Joint Product Cost Function -- The Elasticities of Substitution, Demand, and Marginal Cost

The usefulness of determining the Allen (1938)-Uzawa (1962) partial elasticities of substitution (A-UES) is that they summarize the ease with which one input can be substituted for another without changing any of the outputs or input prices. In other words, the elasticity of substitution determines the proportion of quantities of one input that can be traded for another by movement along the isoquant. A large elasticity of substitution indicates that one input can be easily substituted for another while an elasticity that is close to zero implies that the two inputs are very poor substitutes. Negative elasticities of substitution imply the inputs are complements.

Uzawa (1962) provides the complete derivation of the Allen partial elasticities of substitution adapted to cost function estimation. Briefly, the general form of the elasticity of substitution (σ) becomes:

$$\sigma_{ij} = \frac{C \cdot C_{ij}}{C_i C_j} \tag{2.27}$$

where C is the cost function, C_i and C_j representing partial derivative with respect to P_i and P_j respectively, and C_{ij} is a second partial derivative for $i \neq j$.

The A-UES have been adapted to the translog cost function by many economists such as Christensen and Greene (1976), Berndt and Wood (1975) and (1979), Humphrey and Moroney (1975), Anderson (1979), and Griffin (1977). The form of the elasticities are:

$$\begin{aligned} \sigma_{ij} &= \frac{G_{ij} + S_i S_j}{S_i S_j} \\ \sigma_{ii} &= \frac{G_{ii} + S_i(S_i - 1)}{S_i^2} \end{aligned} \tag{2.28}$$

where S_i and S_j are the factor shares and G_{ij} and G_{ii} are the coefficients of the cross products of the factors. Obviously, from this definition, symmetry must exist between the elasticities, $\sigma_{ij} = \sigma_{ji}$. These definitions do not change for the multiple output case but, due to the content of share equations, the elasticities are expanded so that each σ_{ij} is a function not only of the level of each input price but also the level of each output. In Chapter IV, we provide estimates evaluated at the mean of the actual shares of the six elasticities of substitution.

Another statistic important in an analysis of the structure of production is the input demand elasticity. This permits consideration of how the quantity of one factor demanded will change with respect to a change in its price or that of another factor. Cross-price elasticities and own-price elasticities are respectively:

$$\begin{aligned} E_{ij} &= S_j \sigma_{ij} \\ E_i &= S_i \sigma_{ii} \end{aligned} \tag{2.29}$$

It can be seen that, since E_{ij} is a function of only the factor share of the j^{th} factor, then $E_{ij} \neq E_{ji}$.

The joint cost function in an analysis of production can be used to study substitution elasticities among the outputs. The calculations are identical although the definitions are the inverse of those applied to the inputs. This is due to the independent variables of the cost function consisting of exogenous output quantities and input prices. It is for this reason that the inverse of the elasticity of substitution for the outputs is defined as the percentage change in the output price ratio occurring from a percentage change in the ratio of the output quantities produced. Thus the inverse elasticities of substitution of the outputs are defined as:

$$\pi_{ij} = \frac{D_{ij} + M_i M_j}{M_i M_j}$$

$$\text{and} \quad \pi_{ii} = \frac{D_{ii} + M_i(M_i - 1)}{M_i^2} \tag{2.30}$$

It should, therefore, be remembered that a high value for π_{ij} would indicate that a small change in outputs would cause a large change in output prices, or that the outputs are not easily substitutable.

The π_{ii} can be used to determine the marginal cost elasticities and the inverse of the cross price elasticities for the outputs. These elasticities are defined as:

$$B_{ij} = \frac{\partial \ell n P_i}{\partial \ell n Q_j} = M_j \pi_{ij}$$

$$\text{and} \quad B_{ii} = \frac{\partial \ell n P_i}{\partial \ell n Q_i} = M_i \pi_{ii} \tag{2.31}$$

As with the inputs, all output elasticities will also be evaluated at their means.

Conclusion

It is possible to estimate the parameters of both models through the use of ordinary least squares regression. However, there are several desirable properties of regression analysis that cannot be sacrificed in the interests of simplicity. The most important of these is the ability to measure the applicability of the previously mentioned restrictions on the models.

The statistical technique implemented is the Iterated Zellner Efficient Estimation (IZEF) method. Kmenta and Gilbert (1968) have demonstrated that the parameters estimated through IZEF are identical to those that would be produced through a maximum likelihood procedure for all samples. Ruble (1969) proved the computational equivalence of the two methods. The equivalence of the methods is important since the IZEF will produce the estimates, but the methodology for testing the applicability of the additional constraints is based on maximum likelihood estimation.

CHAPTER III

MODEL SPECIFICATION AND DATA

Introduction

Although the study of the structure and organization of resources in higher education may appear to be a fruitful area for quantitative research, very little empirical analysis has taken place. To be sure, the discipline of higher education administration has produced multitudinous publications in this field. However, these studies have been very limited in their approach. Typically, they attempt to deal only with measuring the concepts of productivity and efficiency. O'Neill (1976), Wallhaus (1975), McGuckin and Winkler (1979), and James (1978) are representative examples of this vast body of literature. In most cases, the studies define productivity along the lines of some measure of unit cost such as dollars of expenditures per student credit hour produced or the student faculty ratio for specific departments or the university as a whole. These measures of unit cost are then compared to the unit costs of other universities which serve as a scale of performance to determine productivity.

There is one study by Verry and Layard (1975) that deserves special consideration because it is the only study that estimates cost functions for university research and teaching. Their approach differs from that presented here in three major aspects. First, they attempt to estimate a total cost function for a group of British universities in total rather than across instructional departments. Second, they are not concerned with the substitutability among the types of academic labor services. (Teachers' salaries are included only as one component of total cost.) Third, research is incorporated into their model as an independent variable and is computed as teachers' time devoted to research rather than an actual measure of output such as journal articles produced. Thus research, an output, is treated as if it were a labor input.

The problems associated with applying economic theory to higher education are best explained in the following statement by James (1978).

> "Ideally, in examining questions of productivity and technology, we would like some index of the learning and increased earning potential imparted by different instructional modes, but these data are generally not available. The prevalence of nonprice rationing, the lack of consumer information, and the possibility of externalities mean that market price cannot be taken as an indicator of marginal social value in higher education. A mechanism for separating the contribution of student time and characteristics and interactions from other inputs has not yet been devised. Teaching quality might, in principle, be approximated by comparing 'before and after' test scores, but these have not been widely adopted. As a result, teaching output has been measured simply in terms of student credit hours or degree candidates of various sorts, abstracting from the quality dimension, by most of the studies referred to in this paper.
>
> "The situation is even worse with respect to

> basic university research which, typically, is not sold on the market at all. Not only are we lacking a subjective quality index, we do not even have a crude quantity index, such as numbers of articles and books, for most disciplines and years. Therefore, quantification of research productivity has rarely been attempted, and most studies simply look at the input side of the picture."

We must agree that many of the problems are, indeed, formidable. The lack of a well-defined marketplace where price and quantity are uniquely determined for every instructional department and every output is not easily solved. However, the use of student credit hours (SCH) as a measure of instructional output remains as the only quantitative measure of a department's teaching load.

The issue of quality can, at best, be minimized by assuming that all of the instructional departments within a university attempt to maintain a level of quality in instruction research that is consistent within the reputation of the university as a whole. Naturally, there are departments that can be considered to be out-lyers to the university's overall reputation. However, without a marketplace to differentiate the departments' outputs, any decisions regarding quality becomes arbitrary. The problem with reporting research output has been solved (although the quality issue is still present). Michigan State University does have fairly accurate records of all journal articles and book publications by the faculty. There is a problem specifying this output because a research article or book is credited to a department only for the year of publication and not the year the research was actually performed. We have addressed this issue by assuming that a department will record its publications in the calendar year following an academic year. For example, the publications for the calendar year, 1978, were assigned to the academic year, 1977-78.

Among the additional difficulties that have faced researchers of the structure of higher education has been the lack of accurate employment records. It has not been until recently that universities have kept faculty records on a full-time equivalency basis. Previously, records on temporary and part-time faculty were recorded only on a headcount basis. Since the percentage distribution of full-time and part-time faculty is not identical across all departments of a university, erroneous results would be produced. At Michigan State University, complete full-time equivalent information for all faculty members exists for only two years -- 1977-78, and 1978-79. Although data exist for the other variables in prior years, it is of little use without accurate full-time equivalencies.

Additionally, the data for both years include only those departments that produced all three outputs. A department reporting a zero for any one output has been dropped from the sample. This is because all outputs (and inputs) are in logarithmic form. Beyond the teaching of students and research, faculty are also expected to participate in public service. Those departments that are considered to have public service as a major output have also been excluded from the sample data.

Appendix A is a listing of which departments are included in the data along with a brief explanation for excluding specific departments. The departments that have been included were chosen to represent a group as similar as possible with respect to both their efficiency and the quality of the outputs. The data are a two-year cross section of sixty-one instructional departments at Michigan State University for the academic years 1977-78, and 1978-79. It would have been preferable to estimate the model over a much longer period of time, say, five to ten years. However, as stated above, the data were simply not available. The source of all data used is the Office of Institutional Research, Michigan State University.

Defining and Measuring the Outputs

The definition and measurement of a unit of output in higher education is a controversial issue. Agreement does not even exist on the precise function of education. Does education produce more qualified individuals or is it nothing more than a screening process? The first function implies that through education an individual's skills are changed, while the second function implies that schools do nothing more than identify the most able individuals in the society. The latter has been the subject of both theoretical treatment (Spence, 1973) and empirical treatment (Taubman and Wales, 1973 and 1974). The differences between the two social functions of education should, theoretically, affect the specification of quality within a model.

Besides not knowing exactly how education should be measured, there is the additional problem of measuring the quality of education. One approach is to measure some change that has occurred in students due to their exposure to the faculty and graduate assistants. This is feasible for instruction, since students could be tested at the end of each term, but it would be impossible to measure the change in total human knowledge based on a single piece of research. Another approach would be to create some arbitrary index of performance to specify the differences in quality, much as one would "grade" the quality of meat or the horsepower of an engine. It is conceivable that an index could be created for research articles; however, any index that would be used would be costly to compile or extremely artibrary (such as asking department chairpersons to judge the quality of their faculty's research). It would also be possible theoretically to index the quality of instruction based on the earnings of graduates. However, this is not possible since it would be difficult to determine which portion of a graduate's salary could be attributed to the specific departments within the university (O'Neill, 1976).

Thus, although we can understand the problems of measurement, we cannot entirely solve them in this study. The outputs of each instructional department are defined as undergraduate student credit hours (Y_U), graduate student credit hours (Y_G), and research (Y_R), (discussed below). Nerlove (1972) describes these as being the relevant outputs produced by the higher education sector. This study will differ from the concepts established by Nerlove in two major aspects. The first is that he classifies research into one of two categories -- basic and applied -- and, further, that graduate education and basic research are perfect compliments. Since the data used in this study do not draw any distinction between basic and applied research, these points cannot be considered.

The undergraduate and graduate student credit hours are three-term academic year totals on a course level basis rather than a student level basis. In other words, if a graduate student majoring in chemical engineering were to take an undergraduate class in economics, his student credit hours would be reported by the Department of Economics in undergraduate student credit hours. The graduate student credit hours include, besides classroom instruction, all doctoral dissertation research credits assigned to that department. Research is defined for the purposes of this study as only the publication of refereed journal articles and books (all other types of publications being ignored). Setting the relative value of one book equivalent to four journal articles and three co-authored books is, admittedly, arbitrary. This ratio represents nothing more than the average of the ratios used by many other authors (Hugine, 1978). Folger and Bayer (1966) describe the use of one weighting method of publications over another by stating, "none of the researchers had an objective or empirical basis for their choice of weights and several admit to subjectivity of the weighting system employed."

The means and variances for each output variable over both years are:

	mean	variance	variance ÷ mean
Undergraduate SCH (Y_U) per department	9585	798	8%
Graduate SCH (Y_G) per department	1631	1554	95%
Research units (Y_R) per department	33	37	112%

Comparing the means and variances above, we find that research has greatest variance relative to its mean (112%). This is followed by graduate SCH (95%) and undergraduate SCH a distant third (8%). Although these large variances are understandable and to be expected, a serious difficulty arises in interpreting the results. The conclusions drawn from the analysis of the production process of higher education is based on various elasticities evaluated at the means of the variables. The statistical technique used to estimate the model's coefficients provides a confidence interval over the entire range of the data. As we move away from the mean we find that the interval increases in width which implies less accuracy in predicting total cost. Therefore, the model's estimates will become more unreliable the farther a particular department's outputs are from the mean of that output.

Obviously, from a statistical perspective, it is desirable to have variables with sizable variance; however, it does tend to weaken the analysis based on the means. It shall be left to future studies with more refined data to estimate the substitutions of the inputs evaluated away from the mean.

Defining and Measuring the Inputs and Cost of Inputs

For the purpose of estimating substitution among the professional labor services of a university, it is necessary to identify and measure these labor inputs on a full-time equivalency basis. This method assumes one full-time equivalent appointment to be forty-hours per week from September 15th to June 15th, without adjustment for vacations or sick leave. In a technical sense, it would be more appropriate to use an annual salary equivalent to an hourly wage rate multiplied by hours actually worked. This would provide a closer relationship between the wages paid for work actually performed and the amount of output produced from that work. However, as described by Blackburn (1974) the collecting of data on the quantity of each labor input used in the production process would be extremely difficult and almost certainly meaningless. There exists a basic inability to distinguish between leisure activities and professional development. If an historian is reading a biography, he is engaged in both leisure and academic pursuits. When a sociologist scans a newspaper, he is inevitably applying what he reads to either his classroom discussions or his scholarly investigations. Free time and work time are often hard to distinguish in the academic professions. It is for this reason that nine-month academic year salaries are used as proxies for a specific price paid for a unit of work.

The faculty salaries reported are assigned to each department on the basis of where the credit hours were produced rather than the administrative department of faculty members. For example, if a professor of economics were to teach a class in the Department of Labor and Industrial Relations, the professor's salary would be assigned to Labor and Industrial Relations rather than Economics. This crossing over between departments does not exist for graduate assistants; therefore, their salaries are assigned to their administrative unit of record. This permits a matched association of student credit hours produced with the faculty member's salary. However, the research publications of the faculty are assigned to only the department paying the largest proportion of faculty member's salary. The method of reporting research by Michigan State University does not permit prorating research across several departments.

Again, we mention that the category of non-tenured faculty includes the tenure stream and temporary faculty.

The tenure stream faculty are hired with the understanding that if they make reasonable progress in their profession, they will be granted tenure at some date in the future, usually six years, at Michigan State University. The temporary faculty are hired only to fill temporary shortages in teaching positions and are assumed not to contribute to the research output of the instructional department. Combining these two types of labor services into one input becomes an important consideration when the policy implications are stated in Chapter VI.

Graduate assistants are not appointed on a ten-month basis at Michigan State University but, rather, on a three-terms-per-year basis. The salaries recorded for graduate assistants, therefore, represent the sum of the three terms adjusted to a forty-hours-per-week full-time equivalency basis.

As stated above, two years of data are included in the sample. The 1977-78 year's data has been increased by seven percent to reflect the average increase in faculty salaries between the years 1977-78 and 1978-79. Individuals receiving salary increases greater or less than seven percent are assumed to have some change in their productivity reflected in this difference.

The means and variances of the inputs and related data are:

	mean	variance	variance ÷ mean
Total cost	\$674,260	\$482,110	71%
Tenured Faculty Cost	407,200	305,457	75%
Non-Tenured Faculty Cost	140,703	115,743	82%
Graduate Assistant Cost	126,356	137,013	108%
Price-Tenured Faculty (P_T)	26,331	2,462	9%
Price-Non-Tenured Faculty (P_N)	16,613	2,382	14%
Price-Graduate Assistants (P_A)	9,585	798	8%

We find in these statistics very little that is unexpected; however, there are two points worth noting. Graduate assistants' salaries have the smallest variance as a percentage of the mean. This is understandable when we consider that their salaries constitute both compensation for services and a stipend to maintain enrollment in a graduate program. Thus, with all graduate students having the same tuition and fee structure, we would expect this portion of their salaries to be the same across all departments. Another reason for the small variance is that departments have less flexibility and smaller salary ranges for graduate assistants than for the faculty. If there is anything surprising about the above average salaries, it is that the variance of non-tenured faculty salaries is not larger. However, this can be explained by remembering that this is not a variance of all non-tenured faculty salaries but only the variance of average non-tenured faculty salaries across departments. It is not for this study to explain the variations in salaries of individuals. This is left for the numerous studies currently available. It is only important here to note the differences across departments.

CHAPTER IV

MODEL ESTIMATION

Introduction

This chapter presents the results of both the Direct Demand Analysis and the Joint Cost Function Analysis in estimating the demand for the inputs to higher education. The results that will be discussed are: 1) the factor demand elasticities for both models, 2) the elasticity of supply for both models, 3) the applicability of model restrictions, such as homogeneity, constant return to scale, symmetry, separability, and the Cobb-Douglas restrictions, 4) the "goodness of fit" of the estimated joint cost function, and 5) the Allen-Uzawa elasticities of substitution for the inputs and outputs (derived only from the joint cost function model).

Direct Demand Constraints

The model was estimated for each year of data with five sets of restrictions imposed. In each case, IZEF estimation was performed with every variable regressed in logarithmic form.[1]

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[1] The computer programming used the Time Series Processor (TSP) Version 2.8 statistical package and was run on the CDC 750 computer at Michigan State University.

Table 4.1 shows the applicable Chi-Square test results for the various restrictions.

The 1977-78 data reflect both homogeneity of input prices and homogeneity with symmetry of the cross price elasticities, while the 1978-79 data can be appropriately specified with only the symmetry constraint.

Comparing the data for both years provides some indication of why the estimates in the direct demand analysis and the joint product cost function (to be discussed later) are so different across the two years (see Appendix B). The cause of the difference is the variable for research (Y_R) and this appears to be the major cause of the different results. There is very little difference in the factor prices after the 1977-78 has been adjusted for inflation at a rate of 7 percent. The reporting of student credit hours for undergraduate and graduate instruction are not much different between the years with only minor exceptions such as Biophysics, Crop and Soil Sciences, and Packaging. Research, on the other hand, is considerably different for many departments between the two years. The Department of Psychology, for example, dropped in publications from 126 in 1977-78, to 65 in 1978-79, while the Department of Crop and Soil Sciences increased its research output from 42 to 159. If we group the departments with the greatest reported changes together, we find they are concentrated in the Colleges of Agriculture and Natural Resources, Arts and Letters, and, to a lesser extent, Natural Science. One

Table 4.1: Direct demand analysis: Chi-Square test of restrictions.

1977-78 Data	Restrictions (Degrees of Freedom)	Chi-Square Test
Homogeneity	3	5.0
Symmetry	3	18.0*
Homogeneity and Symmetry	6	10.8
Constant Returns to Scale	6	80.4*
1978-79 Data		
Homogeneity	3	13.2*
Symmetry	3	6.6
Homogeneity and Symmetry	6	22.6*
Constant Returns to Scale	6	88.0*

* Significantly different from zero at $\alpha = .01$.

possible explanation could be that the research occurring in the Colleges of Natural Science and Agriculture and Natural Resources is more directed toward scientific experimentation which requires long periods of testing and data collection in laboratories. Thus, we reason that this would cause the research to be highly variable in these colleges. We would expect these year-to-year differences to be minimal when the data are aggregated to the departmental level but apparently they are not. Whatever the actual or assumed cause of the wide variation in publications from year to year, there is no doubt that the ability of the model to replicate the structure of academic labor services would be improved with better specification of research output. Pooling data over a period of several years would reduce the model's sensitivity to research cycles. This cannot be done now because only two years of data are currently available.

Direct Demand Estimates -- The Inputs

The estimates for the structure of higher education, although not consistent, can provide valuable insight into the production process. Rather than discuss the wide range of results presented by each model, we will concentrate on the most restrictive case that is applicable to the system, the 1977-78 data with homogeneity of input prices and symmetry of cross price elasticities.

Table 4.2 presents the regression estimates and the applicable constraints. The elasticities of demand for the

Table 4.2: Direct demand estimates: Price coefficients (t-test in parentheses).

Demand Elasticities	1977-78 Data: Unrestricted[1]	1977-78 Data: Homogeneity[2]	1977-78 Data: Symmetry & Homogeneity[3]	1978-79 Data: Unrestricted[1]	1978-79 Data: Symmetry[4]
E_T	-1.74 (2.30)	- .38 (.63)	-1.15 (1.99)	-1.29 (1.54)	-1.14 (1.38)
E_N	-1.07 (1.39)	-1.07 (1.39)	-1.28 (1.83)	- .07 (.10)	- .17 (.28)
E_A	.13 (.12)	1.83 (2.31)	-4.01 (5.27)	- .16 (.20)	- .32 (.39)
E_{NA}	2.44 (2.01)	2.44 (2.85)	2.07 (4.27)	- .02 (.02)	-1.54 (3.28)
E_{AN}	- .45 (.65)	- .36 (.50)		-1.63 (2.70)	
E_{NT}	-1.37 (1.18)	-1.36 (.40)	- .79 (1.78)	-2.21 (1.92)	1.23 (2.65)
E_{TN}	- .69 (1.36)	- .66 (1.31)		-1.15 (2.28)	
E_{TA}	1.61 (2.03)	2.04 (3.36)	1.94 (5.37)	.62 (.92)	- .09 (.16)
E_{AT}	-2.89 (2.80)	- .47 (.56)		-1.19 (1.19)	

[1] Estimates determined by regression equations 2.6; output coefficients appear in Table 4.3.

[2] Estimates determined by regression equations 2.7; output coefficients appear in Table 4.3.

[3] Estimates determined by regression equations 2.13; output coefficients appear in Table 4.3.

[4] Estimates determined by regression equations 2.12; output coefficients appear in Table 4.3.

three types of labor services are all negative and sufficiently large in size so that demand may be described as highly elastic (E_T = -1.15, E_N = -1.28, E_A = -4.01). Recall that in the demand equations the amount demanded for each input was a function of input prices and the output quantities. Therefore, a 1 percent increase in tenured faculty salaries, for example, would cause a 1.15 percent decrease in the number of tenured faculty employed. The relative sizes of the estimates indicate that the input with the greatest elasticity is graduate assistant employment. These individuals have not had the time or experience in their discipline to establish a reputation and could be considered to be in a competitive market with all graduate students for their assistantships. Tenured faculty, on the other hand, have more years experience, and have established areas of experitise that makes the demand for their services far more unique. Thus, we see nation-wide searches carried out by departments interested in filling tenured faculty vacancies while the same departments choose their new graduate assistants from the applications received annually with very little solicitation. In terms of economic theory, the tenured faculty have (successfully) differentiated their product of labor services more effectively than either the non-tenured faculty or graduate assistants. The non-tenured faculty have also provided more differentiation of their product than graduate assistants since they have completed a doctoral program and, in most cases, have specialized in several areas within their discipline.

Because of the large standard errors, the cross price elasticities do not provide estimates from which clear implications can be drawn. As expected, graduate assistants are easy substitutes for both the tenured faculty (E_{TA} = 1.94) and the non-tenured faculty (E_{NA} = 2.07) because we had assumed in Chapter I that the substitution would be greater than complementarity. These results indicate that a 1 percent change in the salaries of either of the two faculty categories will cause approximately a 2 percent increase in the number of graduate assistants employed and tell us that administrators are quite willing to employ graduate assistants if the salaries of the faculty rise sharply. The explanation for these results is that the graduate assistants' contribution to undergraduate instruction rather than research or graduate instruction cause the substitution with the faculty. As stated in Chapter I, the apparent reason for these findings is the unsupervised instruction by graduate assistants and the use of large lectures with one faculty member and several graduate assistants to replace hiring more faculty members. Obviously, the same argument applies to the high cross price elasticity between the non-tenured faculty and graduate assistants.

The other cross-price elasticity between tenured and non-tenured faculty (E_{TN} = -.79) is contrary to what we expected. We expected that the non-tenured faculty, consisting of both temporary and tenure stream employees, could be easily substituted for tenured faculty since the responsibilities of instruction and research are generally shared. However, this inconsistency can be explained by considering the importance of research to the non-tenured faculty. Most of these individuals are attempting to advance their careers in their profession (and gain tenure). However, as we stated in Chapter III, the variable "research output" does contain some misspecification due to time lags in reporting publication. Therefore, we find it reasonable to conclude that the misspecification of research is the cause for the non-tenured faculty to appear as substitutes for graduate assistants and complements to the tenured faculty. There is one possible explanation for the complementarity between the tenured and non-tenured faculty. It must be assumed that, with respect to instruction, both graduate and undergraduate are substitutes and, therefore, any complementarity that exists must occur within research. We can argue that the role of the tenured faculty in research is one of generating their own projects along with providing assistance to the non-tenured faculty in attaining research grants and developing proposals for research topic. Thus, although the tenured faculty may or may not provide much assistance to the non-tenured faculty, the tenured faculty may play a very important role in supporting the non-tenured faculty research. Although the non-tenured faculty may do all of the data collection, development of analysis, and writing the research articles, it is the professional sophistication of the tenured faculty that initially generates the design and feasibility of project. It is difficult to estimate which of the two explanations above contributes most to the complementarity; however, it does seem that together they overshadow the effects of substitution related to instruction.

Direct Demand Estimates -- The Outputs

The direct demand analysis also provides estimates of the returns to scale appearing in Table 4.3. These results are much more consistent across all of the model restrictions and for both years of data than were the estimates of price elasticities. Returning to the constrained model of homogeneity of input prices and symmetry of the cross-price elasticities, the sum of the output coefficients for tenured and non-tenured faculty and graduate assistants are .60, .43, and .91 respectively. Increasing each output simultaneously by some fixed percentage, say 1 percent, will cause a less than one percent increase in employment for all three types of labor services. The largest increase in employment occurs with the graduate assistants. This can be explained by the argument that graduate assistants, in general, contribute to the outputs only as support personnel to the faculty. Thus as faculty teaching loads increase and the average class size increases, there would be more graduate assistants employed and assigned to each faculty member. The output of the faculty appears greater, implying greater scale economies while the graduate assistants exhibit far smaller

Table 4.3: Direct demand estimates: Output coefficients (t-test statistics in parentheses).

	1977-78 Data			1978-79 Data	
Tenured	Unrestricted[1]	Homogeneity[2]	Symmetry & Homogeneity[3]	Unrestricted[1]	Symmetry[4]
ℓnY_U	.15	.15	.16	.23	.24
	(2.06)	(2.01)	(2.15)	(3.13)	(3.17)
ℓnY_G	.12	.12	.11	.18	.18
	(1.64)	(1.53)	(1.43)	(2.93)	(2.88)
ℓnY_R	.35	.34	.33	.33	.33
	(4.93)	(4.87)	(4.94)	(4.82)	(4.91)
Sum	.62	.61	.60	.74	.75
Non-Tenured					
ℓnY_U	.08	.08	.11	.23	.23
	(.72)	(.72)	(.93)	(2.21)	(2.22)
ℓnY_G	.18	.18	.16	.16	.14
	(1.51)	(1.53)	(1.38)	(1.97)	(1.66)
ℓnY_R	.18	.18	.16	.13	.12
	(1.64)	(1.65)	(1.56)	(1.39)	(1.42)
Sum	.44	.44	.43	.53	.50
Graduate Assistants					
ℓnY_U	.04	.03	.05	.17	.16
	(.43)	(.27)	(.50)	(1.87)	(1.79)
ℓnY_G	.28	.24	.18	.33	.30
	(2.66)	(2.25)	(1.65)	(4.46)	(4.01)
ℓnY_R	.69	.68	.68	.41	.40
	(4.23)	(6.85)	(7.43)	(5.15)	(5.14)
Sum	1.01	.95	.91	.91	.86

Table 4.3: Continued.

Sum of Coefficients across equations	1977-78 Data: Unrestricted[1]	1977-78 Data: Homogeneity[2]	1977-78 Data: Symmetry & Homogeneity[3]	1978-79 Data: Unrestricted[1]	1978-79 Data: Symmetry[4]
ℓnY_U	.27	.26	.32	.63	.63
ℓnY_G	.58	.54	.45	.51	.62
ℓnY_R	1.22	1.20	1.17	.87	.85

[1] Estimates determined by regression equations 2.6; input coefficients appear in Table 4.2.

[2] Estimates determined by regression equations 2.7; input coefficients appear in Table 4.2.

[3] Estimates determined by regression equations 2.13; input coefficients appear in Table 4.2.

[4] Estimates determined by regression equations 2.12; input coefficients appear in Table 4.2.

scale economies.

Additionally, we should note that in the demand for graduate assistants the coefficient on graduate instruction (Y_G = .18) is more than three times greater than the coefficient on undergraduate instruction, Y_U = .05, as shown in Table 4.3. It is not reasonable that increasing graduate instruction would cause an increase in the number of graduate assistants since we assumed their contribution to graduate teaching was negligible. It is more likely that the strong correlation is due to the dual role graduate assistants play in the production process as inputs and as contributors to the output of graduate instruction. Increasing the size of a graduate program would require increasing the number of assistants available since the assistantships are partially a stipend to induce students into starting the graduate program. Therefore, the larger graduate programs invariably provide more graduate assistantships. There is another aspect to the correlation between graduate instruction and graduate assistants that should be discussed. A department that is experiencing a sizable increase in the demand for its undergraduate programs will hire graduate assistants to do the teaching. Increasing the number of graduate assistantships will, in turn, increase the size of the graduate program. Thus, we see an increase in the undergraduate program has the spill-over effect of increasing the graduate program simultaneously. Conversely, when undergraduate enrollments decline, we can expect the graduate programs at colleges and universities to also decline. We also see from Table 4.3 that if all of the outputs were to rise by the same proportion, say 10 percent, there would be a greater increase in the demand for tenured faculty (6.0 percent) than in the demand for non-tenured faculty (4.3 percent). We could argue that increasing the outputs would require a greater increase in the demand for the non-tenured faculty than tenured faculty because the non-tenured faculty are in their prime research and publishing years and increased research would significantly increase the demand for their services. However, the coefficient on research (Y_R = .16) in the non-tenured faculty demand equation is approximately one-half that of the corresponding coefficient (Y_R = .33) in the tenured faculty equation. Again, this appears to be another form of the misspecification of research causing the estimates related to the non-tenured faculty to be unreasonable.

If we add the coefficients for each output variable across the three demand equations, we have the following estimates of the total impact of each output on employment (using the 1977-78 data and the constraints of homogeneity and symmetry from Table 4.3).

$$Y_U = .32$$
$$Y_G = .45$$
$$Y_R = 1.17$$

These statistics imply that, if each output is increased by the same percentage, total employment will be increased by the smallest percentage from undergraduate instruction with much larger increases from graduate instruction and a still larger increase in employment from research. These results reflect the ability of departments to increase instruction through the use of large lecture halls and televised instruction. Graduate instruction is found to have roughly the same effect on the employment of both types of faculty as undergraduate instruction. This result implies that it is possible, from the supply side of the output market, to adapt some of the scale economies such as large lectures and televised instruction used in undergraduate teaching to graduate programs. However, it is unlikely that graduate enrollments (the demand side) are large enough to make this feasible. The employment diseconomies associated with research can be explained when we look at ℓnY_R in each of the three equations.

Demand Equation	ℓnY_R
Tenured Faculty	.33
Non-Tenured Faculty	.16
Graduate Assistants	.68

From the above table we see the greatest increase in demand occurs with graduate assistants. It is possible that the total cost of research can decline as departments shift their labor resources to research since the cost of an additional graduate assistant is cheaper than a faculty member. The graduate assistants then provide their services for reviewing the literature, data collection, and any computer programming that might be necessary. These laborious and time consuming tasks are no longer the responsibility of the faculty member, thus making his or her time more valuable and requiring less of an increase in faculty employment.

Direct Demand Estimates -- The Three Year Rate of Adjustment

It is also important in the study of higher education to gain some understanding of how departments adjust their inputs to some optimal level when there is an exogenous change in the outputs. The analysis up to this point has assumed that each department is capable of adjusting its inputs instantaneously at the beginning of each academic year. Obviously, this is not possible for most, if any, departments. For the purposes of further developing this study, we assume that the departments at Michigan State University base their employment decisions only on the instruction and research in the current year and differences between the amount of current instruction, both undergraduate and graduate, and level of instruction three years prior. The direct demand analysis can be adapted to include consideration of the adjustment process through the addition of two terms in each regression equation. The theoretical form of these equations with the constraints of symmetry and homogeneity (adapted from equation 2.13) are:

$$\ell nL_T = \hat{A}_1+\hat{B}_1\ell n(P_T/P_A)+\hat{B}_2\ell n(P_N/P_A)+\hat{C}_1\ell nY_U+\hat{C}_2\ell nY_G+\hat{C}_3\ell nY_R$$
$$+D_1(\ell nY_U-\ell nY_{U-3})+D_2(\ell nY_G-\ell nY_{G-3})+\hat{E}_1+\hat{e}_1$$
$$\ell nL_N = \hat{A}_2+\hat{B}_2\ell n(P_T/P_A)+\hat{B}_4\ell n(P_N/P_A)+\hat{C}_4\ell nY_U+\hat{C}_5\ell nY_G+\hat{C}_6\ell nY_G \quad (4.1)$$
$$+D_3(\ell nY_U-\ell nY_{U-3})+D_4(\ell nY_G-\ell nY_{G-3})+\hat{E}_2+\hat{e}_2$$
$$\ell nL_A = \hat{A}_3+\hat{C}_7\ell nY_U+\hat{C}_8\ell nY_G+\hat{C}_9\ell nY_R+D_5(\ell nY_U-\ell nY_{U-3})+D_6(\ell nY_G-\ell nY_{G-3})$$
$$+\hat{E}_3+\hat{e}_3$$

where $\hat{B}_2 = -(\hat{B}_1 + \hat{B}_2)$

$\hat{B}_6 = -(\hat{B}_4 + \hat{B}_5)$

and $\hat{B}_9 = -(\hat{B}_7 + \hat{B}_8)$

and Y_{U-3} and Y_{G-3} are the lagged output variables of undergraduate and graduate instruction respectively. These regression equations can be altered slightly to produce a system of equations that will reduce the number of calculations necessary in deriving the coefficients. The actual regression equations are:

$$\ell nL_T = \hat{A}_1+\hat{B}_1\ell n(P_T/P_A)+\hat{B}_2\ell n(P_N/P_A)+E_1\ell nY_U+E_2\ell nY_G+\hat{C}_3\ell nY_R$$
$$-D_1\ell nY_{U-3}-D_2\ell nY_{G-3}+\hat{E}_1+\hat{e}_1$$
$$\ell nL_N = \hat{A}_2+\hat{B}_2\ell n(P_T/P_A)+\hat{B}_4\ell n(P_N/P_A)+E_3\ell nY_U+E_4\ell nY_G+\hat{C}_6\ell nY_R \quad (4.2)$$
$$-D_3\ell nY_{U-3}-D_4\ell nY_{G-3}+\hat{E}_2+\hat{e}_2$$
$$\ell nL_A = \hat{A}_3+E_5\ell nY_U+E_6\ell nY_G+\hat{C}_9\ell nY_R-D_5\ell nY_{U-3}-D_6\ell nY_{G-3}+\hat{E}_3+\hat{e}_3$$

where: $E_1 = (\hat{C}_1 - D_1)$ $\qquad$ $E_4 = (\hat{C}_4 - D_4)$

$E_2 = (\hat{C}_2 - D_2)$ $\qquad$ $E_5 = (\hat{C}_5 - D_5)$

$$E_3 = (\hat{C}_3 - D_3) \qquad E_6 = (\hat{C}_6 - D_6)$$

The coefficients D_j are defined as the estimates of the rate of change in the demand for a particular labor input based on the exogenous change in an instructional output. For example, if undergraduate instruction were to be 1 percent greater in the academic year 1977-78, than in 1974-75, the coefficient D_1 would estimate the percentage change in demand for tenured faculty. If D_1 were very small in value and not statistically significant, this may indicate that the departments can instantaneously adjust the number of tenured faculty employed. Although this may appear to be a reasonable conclusion, it is obviously wrong. It is far more reasonable to believe that, if D_1 is insignificant, it is due to the adjustment in the demand for tenured faculty being greater (or less) than three years. No one believes that every department within the university can instantaneously adjust any of the three types of academic labor services. Rather, it is a shortcoming of the model since it cannot accurately determine the appropriate time lag required for adjustment. The coefficients on the current level of output (E_i) is the sum of both the long-term equilibrium effects of current changes on the demand for particular input and the three-year rate of adjustment.

Table 4.4 shows all of the coefficients estimated from the system of equations in (4.2). Included in this table, for purposes of comparison, are the estimates of the same model discussed previously (equation 2.13) with the lagged

Table 4.4: Direct demand estimates: Model coefficients with lagged instructional variables, included and excluded, 1977-78 data with homogeneity and symmetry constraints (t-test statistics in parentheses).

		Model Including Lagged Variables	Model Excluding Lagged Variables
Dependent Variable: Number of Tenured Faculty Employed Coefficient on:			
Price of Tenured Faculty	$(\hat{B}_1)$	-1.13 (1.97)	-1.15 (1.99)
Price of Non-Tenured Faculty	$(\hat{B}_2)$	- .76 (1.72)	- .79 (1.78)
Price of Graduate Assistants	$(\hat{B}_3)$	1.90 (3.44)	1.94 (5.37)
Undergraduate SCH	(E_1)	.14 (1.77)	.16 (2.15)
Graduate SCH	(E_2)	.11 (1.38)	.11 (1.43)
Research	$(\hat{C}_3)$	.32 (4.66)	.33 (4.84)
Lagged Undergraduate SCH	(D_1)	- .05 (.67)	N/A
Lagged Graduate SCH	(D_2)	- .004 (.04)	N/A
Dependent Variable: Number of Non-Tenured Faculty Employed Coefficient on:			
Price of Tenured Faculty	$(\hat{B}_2)$	- .76 (1.72)	- .79 (1.78)
Price of Non-Tenured Faculty	$(\hat{B}_4)$	-1.18 (1.65)	-1.28 (1.83)
Price of Graduate Assistants	$(\hat{B}_6)$	1.94 (2.66)	2.07 (4.27)
Undergraduate SCH	(E_3)	.07 (.56)	.11 (.93)
Graduate SCH	(E_4)	.18 (1.52)	.16 (1.38)
Research	$(\hat{C}_6)$	.14 (1.37)	.16 (1.52)
Lagged Undergraduate SCH	(D_3)	- .10 (.85)	N/A
Lagged Graduate SCH	(D_4)	.07 (.58)	N/A

Table 4.4: Continued.

		Model Including Lagged Variables	Model Excluding Lagged Variables
Dependent Variable: Number of Graduate Assistants Employed Coefficient on:			
Price of Tenured Faculty	($\hat{B}_3$)	1.90	1.94
		(3.44)	(5.37)
Price of Non-Tenured Faculty	($\hat{B}_6$)	1.94	2.07
		(2.66)	(4.27)
Price of Graduate Assistants	($\hat{B}_9$)	-3.85	-4.01
		(4.01)	(5.27)
Undergraduate SCH	(E_5)	.14	.05
		(1.37)	(.50)
Graduate SCH	(E_6)	.09	.18
		(.83)	(1.65)
Research	($\hat{C}_9$)	.74	.68
		(8.42)	(7.43)
Lagged Undergraduate SCH	(D_5)	.28	N/A
		(2.72)	
Lagged Graduate SCH	(D_6)	- .26	N/A
		(2.60)	

instructional variables excluded. In this table, we see very little difference in the estimates of the demand for tenured and non-tenured faculty. The lagged variable terms (Y_{U-3} and Y_{G-3}) are very small and not significant at the $\alpha = .05$ level. Only in the demand for graduate assistants equation are both of the lagged variables on instruction (D_5 and D_6) significant.

Overall, the estimates of the direct demand equations, modified to include estimates of the rate of adjustment, are quite reasonable because the only significant lagged variables appear in the demand for graduate assistants equation. We can assume that adjustment in the demand for tenured and non-tenured faculty is not three years but probably a greater period of time. Departments can easily make changes to the number of graduate assistants employed since they are only hired on a year to year basis with the average length of a graduate program being three years. Many non-tenured faculty are in the tenure stream and are assumed, for planning purposes, to have continuing employment which would imply an adjustment longer than three years. Changes in the demand for the tenured faculty would be assumed to require the greatest time since normal attrition and lengthy nation-wide searches are typically necessary for changes in tenure faculty employment.

Returning to the demand for graduate assistants, the changes in the non-lagged coefficients are negligible. However, the estimates of the rate of adjustment do provide some unusual results. This would imply that, when the graduate and undergraduate program is growing over a three-year period, the demand for graduate assistants would increase. The reasons for this are obvious. As undergraduate instruction increases, class sizes would increase and more graduate assistants would be employed to assist the faculty. This is consistent with the model's estimates with D_5 equal to .28. We previously discussed a positive correlation between the size of a graduate program and the number of graduate assistant appointments; therefore, we would expect to find an increasing graduate program would increase the demand for graduate assistants. However, the estimate of the rate of adjustment in the demand for graduate assistants from changes in the graduate program is negative ($D_6 = -.26$). This implies that increasing the size of a graduate program causes a decline in the demand for graduate assistants. One possible explanation of why this coefficient should be negative is that the use of a three-year lagged variable on graduate instruction is not appropriate.

The Joint Cost Function Equations and Tests of the Constraints

In this approach to modeling the structure of higher education, we first estimate the underlying cost function parameters. These, in turn, are used to derive the elasticities of substitution, output supply, and factor demand. However, before our conclusions can be drawn regarding the production process, the exact specification of the cost function model must first be determined. Recall from Chapter II that there is a cost function and four possible share equations that can be included in the regression model. Thus there are four possible methods for specifying the model. Each method produces all of the parameter estimates necessary for analysis. The four methods are:

1. The cost function only;
2. The cost function and two input share equations;
3. The cost function and two input and two output share equations; and
4. The two input and the two output share equations only.

The choice of which of the above four is "best" is made from two requirements: 1) which set of equations maximizes the likelihood function; and 2) which set of estimates satisfies the first- and second-order conditions.

Table 4.5 contains the values of the logarithmic likelihood functions for each of the four methods for both 1977-78 and 1978-79. In the two years under study, the likelihood function is maximized when the system of regression equations consists only of the four share equations (method 4 above).

Next the conditions of monotonicity and convexity must be checked. Monotonicity exists if $\frac{\partial C}{\partial P_i}$ and $\frac{\partial C}{\partial Y_j}$ are greater than zero. An equivalent condition is that every M_j and S_i is greater than zero and less than one. The convexity condition, as previously stated, is satisfied if the Hessian

Table 4.5: Joint cost function: Log of the likelihood functions.

Regression Model	1977-78 Data	1978-79 Data
Four Share Equations only	218.5*	228.8
Cost Function only	.41	7.4
Cost Function and four Share Equations	188.6	190.9
Cost Function and two Input Share Equations	98.5	103.4

* Denotes positive shares for both inputs and outputs and that the second order condition is reasonably satisfied.

matrix is negative semi-definite. These regularity conditions were tested for each year and each set of equation systems. The results were less than encouraging. The conditions were reasonably met only with the four share equations (excluding the cost function) and for only the 1977-78 data year. In this set of regression equations the conditions were tested using both fitted factor shares and actual factor shares. When fitted input and output shares were used, the regularity conditions were satisfied for 50 to 59[2] departments. The actual input and output shares met the regularity conditions for 40 out of the 59 departments. In the other possible systems of regression equations where the first-order conditions are met, none of the regularity conditions were met. In the set of equations where the fitted shares were acceptable, the determinants of the bordered Hessian matrix were of the wrong sign. The inability of the model to produce acceptable results was also evident in the 1978-79 data. None of the four possible systems of regression equations could produce results that were consistent with the conditions of convexity for a well-behaved cost function.

The inadequacy of the data to satisfy the necessary conditions for analysis is, in general, due to the changing

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[2] Two additional departments were dropped from the 1977-78 data due to zeros appearing in their output values. See Appendix A for a listing of the included departments for each year's data.

of sign of several of the many insignificant variables involved in calculations. In Table 4.6, we see the number of coefficients significant at the α = .05 level ranges from a low of 8 to a high of 15 out of a possible 29 coefficients. The instability of the coefficients affects the model in two ways. First, in the cases where all of the shares are not in the regression system, it produces fitted shares that are not acceptable. A model with these results is of little value since, for example, it is not possible for undergraduate SCH to contribute to total revenue by more than 100 percent and research cannot contribute to revenue by some negative amount. Thus without reasonable factor shares, the estimates of the elasticities are not valid. Second, in those cases where the fitted shares were acceptable, the second-order conditions were not met. This was due primarily to the estimates of the own-elasticities of substitution, defined as $\sigma_{ii} = \frac{G_{ii} + S_i(S_i - 1)}{S_i^2}$ where the G_{ii} were positive although not significantly different from zero. There is another problem with the model when the σ_{ii} are estimated to be positive. Since the demand elasticities, defined as:

$$E_{ii} = \frac{\partial \ell n Y_i}{\partial \ell n P_i} = S_i \sigma_{ii} \tag{4.3}$$

are a function of the σ_{ii} and the always positive S_i, an estimated value of a σ_{ii} greater than zero will cause a positively sloped demand curve. Obviously, this result is

Table 4.6: Parameter estimates for the joint translog cost function: 1977-78 data and four share equations only (t-test statistics in parentheses).

Coefficient on	Unrestricted	Homogeneity of outputs	Separability	Homogeneity & Separability	Cobb-Douglas
ℓnY_U	-.349 (2.20)	-.399 (4.19)	-.366 (2.43)	-.366 (4.22)	.415 (16.1)
ℓnY_G	-.019 (.18)	.154 (2.57)	-.020 (.198)	.150 (2.81)	.205 (17.29)
ℓnY_R	1.37 (7.91)	1.24 (11.7)	1.39 (8.49)	1.22 (12.6)	.379 (14.35)
ℓnP_T	.491 (2.17)	.563 (2.84)	.581 (5.26)	.583 (5.25)	.602 (32.56)
ℓnP_N	.361 (1.91)	.059 (.37)	.220 (2.78)	.201 (2.62)	.223 (12.58)
ℓnP_A	.148 (1.10)	.378 (2.96)	.199 (2.06)	.209 (2.15)	.174 (14.68)
$(\ell nY_U)^2$	.136*	.147 (9.47)	.136*	.143 (9.53)	ϕ
$\ell nY_U x \ell nY_G$	-.019 (1.57)	-.033 (3.24)	-.019 (1.64)	-.032* (3.26)	ϕ
$\ell nY_U x \ell nY_R$	-.128 (6.64)	-.114 (8.04)	-.129 (7.07)	-.110 (8.11)	ϕ
$(\ell nY_G)^2$	.067 (5.34)	.061 (4.87)	.068 (5.47)	.063 (5.16)	ϕ
$\ell nY_G x \ell nY_R$	-.024 (2.21)	-.028 (2.69)	-.025 (2.39)	-.031 (3.08)	ϕ

Table 4.6: Continued.

Coefficient on	Unrestricted	Homogeneity of outputs	Separability	Homogeneity & Separability	Cobb-Douglas
$(\ell nY_R)^2$	.134 (7.17)	.143 (8.22)	.128 (7.22)	.142 (8.56)	ϕ
$(\ell nP_T)^2$	.145 (.082)	.105 (.619)	.103 (.69)	.094 (.64)	ϕ
$\ell nP_T x \ell nP_N$	-.069 (.51)	-.098 (.73)	-.150 (1.28)	-.137 (1.18)	ϕ
$\ell nP_T x \ell nP_A$	-.076 (.76)	-.007 (.07)	.047 (.49)	.043 (.44)	ϕ
$(\ell nP_N)^2$	-.074 (.54)	.154 (1.11)	.280 (2.23)	.279 (2.24)	ϕ
$\ell nP_N x \ell nP_A$	-.004 (.06)	-.057 (.67)	-.129 (1.62)	-.142 (1.77)	ϕ
$(\ell nP_A)^2$	.080 (.81)	.064 (.59)	.082 (.77)	.099 (.91)	ϕ
$\ell nY_U x \ell nP_T$	.003 (.13)	.002 (.09)	ϕ	ϕ	ϕ
$\ell nY_U x \ell nP_N$	-.001 (.06)	.018 (.88)	ϕ	ϕ	ϕ
$\ell nY_U x \ell nP_A$	-.002 (.15)	-.016 (1.18)	ϕ	ϕ	ϕ
$\ell nY_G x \ell nP_T$	-.006 (.26)	-.0002 (.007)	ϕ	ϕ	ϕ

Table 4.6: Continued.

Coefficient on	Unrestricted	Homogeneity of outputs	Separability	Homogeneity & Separability	Cobb-Douglas
$\ell nY_G x \ell nP_N$	.006 (.30)	.016 (.77)	ϕ	ϕ	ϕ
$\ell nY_G x \ell nP_A$	-.0001 (.008)	-.016 (1.13)	ϕ	ϕ	ϕ
$\ell nY_R x \ell nP_T$	.006 (.25)	.002 (.10)	ϕ	ϕ	ϕ
$\ell nY_R x \ell nP_N$	-.049 (2.45)	-.033 (1.72)	ϕ	ϕ	ϕ
$\ell nY_R x \ell nP_A$	.043 (3.51)	.031 (2.49)	ϕ	ϕ	ϕ
	=218.5	=210.6	ϕ	ϕ	ϕ

* Denotes supplied at mean of variables not calculated.

not feasible in the context of microeconomic theory since it implies an increasing marginal rate of factor substitution. That is, the estimated cost function is not well-behaved.

Fortunately, the conditions of a maximized likelihood function and satisfactory first- and second-order conditions are met simultaneously for the year 1977-78. This occurs when the system of regression equations consists of only the four share equations. Table 4.6 presents the maximum likelihood estimates of the unrestricted translog joint cost function and four restricted specifications of homogeneity, separability, homogeneity and separability, and Cobb-Douglas form.

Table 4.7 presents the Chi-Square test statistics for each of the four restrictive cases. As shown by this table, none of the restrictive forms are applicable, although homogeneity of outputs is barely rejected. The analysis of the structure of the academic labor services of higher education will, therefore, be based solely on the 1977-78 data year and the unrestricted model of four share equations.[3] The discussion of the direct demand analysis involving the considerable differences in the reported research output between the two years is also applicable to the joint cost function. It appears, from Appendix B, that the research output share does not change significantly between the two years; however, there is a large change in the research publications. This,

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[3] Except for linear homogeneity in factor prices.

Table 4.7: Joint cost function: Test statistics for restricted models, 1977-78 data - four share equations only.

	Test Statistic	Number of Restrictions (Degrees of Freedom)	Critical Level Significance Level
Homogeneity of Outputs	15.8	4	13.3
Separability	19.2	6	16.8
Homogeneity & Separability	23.2	8	20.1
Cobb-Douglas	99.2	14	29.1

again, may be due to the problem of having only two years of data and the highly variable nature of research projects.

There are two coefficients in the unrestricted model that cause some concern. The values of A_U and A_G are less than zero. This indicates that as undergraduate and graduate instruction increases, total cost will decline. The sign of the coefficient on graduate instruction ($\ell nY_G = -.019$) is of lesser importance since the t-statistic indicates that this variable is highly insignificant. However, the coefficient of ℓnY_U of $-.349$ is significant at the $\alpha = .05$ level. From a theoretical standpoint, there is no reason why this should occur. The only rational explanation must come from the fact that there are 27 independent variables in the system which burden the model and cause this estimate to occur. With respect to the first-order input variables, all three coefficients are positive, and two of the three are significant. These results show that the model does reflect positive marginal costs. The second-order cross product terms have coefficients that are, at best, obscure in meaning. Therefore, it is preferable to base the analysis on the elasticities derived from these coefficients. Estimates of the demand, supply, and substitution elasticities are evaluated at the mean of observations over all departments in the sample.

The Joint Product Cost Function Estimates -- The Inputs

Table 4.8 summarizes the demand, cross-price, and substitution elasticities for each of the inputs. The elasticities of substitution are all positive and in agreement with what we expected. The easiest substitution is between graduate assistants and non-tenured faculty (σ_{NA} = .886). Next is the substitution elasticity between tenured and non-tenured faculty, σ_{NT} = .87, with the weakest substitution, σ_{AT} = .276, occurring, as expected, between tenured faculty and graduate assistants. The input elasticities of substitution are of special importance because they imply a structure for the academic labor services that is consistent with what we had assumed in Chapter I. If we believe these estimates are reliable, we must be careful in interpreting the results because several implications are possible. Graduate assistants, for example, are fairly easily substitutable with the non-tenured faculty (σ_{NA} = .886). We could, incorrectly, interpret this to mean that the non-tenured faculty must be providing services that are in most respects similar to those of graduate assistants. Therefore, it can be concluded that the contribution to research by the non-tenured faculty must be minimal. However, we believe that these results may be unreliable because the data do not accurately specify the research output, which is important to the tenured and non-tenured faculty. Additionally, recall that the category of non-tenured faculty was defined to include temporary and tenure stream faculty members. If

Table 4.8: Joint cost function: Estimates of elasticities, 1977-78 data.

Part A. Input Elasticities of Substitution

$\sigma_{NN} = -1.97$	$\sigma_{NA} = .886$
$\sigma_{AA} = -2.09$	$\sigma_{NT} = .487$
$\sigma_{TT} = -\ .260$	$\sigma_{AT} = .276$

Part B. Demand Elasticities

$E_{TT} = -.16$

$E_{NN} = -.44$

$E_{AA} = -.36$

Part C. Cross Price Elasticities

$E_{TN} = .109$	$E_{TA} = .048$	$E_{NA} = .155$
$E_{NT} = .293$	$E_{AT} = .166$	$E_{AN} = .198$

NOTE: These elasticities are derived from coefficients estimated from the share equations (2.18 and 2.20).

the non-tenured faculty were to include only the temporary faculty, we would believe these results to be more reasonable. This point can be restated from another perspective when we look at the substitution possibilities between the tenured faculty and graduate assistants (σ_{AT} = .276), and between the tenured and non-tenured faculty (σ_{NT} = .487). As expected, σ_{AT} is very low, which implies that they are not very good substitutes.

The demand elasticities in Part B, Table 4.8, are consistently negative and all imply highly inelastic demand curves. These extremely low estimates of elasticity (E_{TT} = -.16, E_{NN} = -.44, E_{AA} = .-36) are some cause for concern since the difference is caused by the coefficients needed to estimate the own-elasticity of substitution of the inputs. The coefficients G_{TT}, G_{NN}, G_{AA} are all found to have t-statistics less than one. It would appear that, given these results, the inelastic demand for the inputs is due to the inability of the rather burdened joint cost function to produce significant coefficients. Nevertheless, the model is capable of reasonably meeting all of the conditions of a well-behaved cost function <u>and</u> producing downward sloping demand curves. The fact that the slope is unusually steep is unfortunate but not expected. If we were to interpret these results as if they were statistically reliable, we would draw conclusions opposite to those from the direct demand analysis. These results indicate that the departments are not concerned with prices paid but only quantities of each type of labor they need (since the supply curve is assumed to be perfectly elastic -- it determines factor prices). Additionally, the inelastic demand curve implies each input is uniquely differentiated from the other inputs and does not have a close substitute. This obviously contradicts the rather high elasticity of substitution estimated for graduate assistants and the non-tenured faculty.

The cross-price elasticity appearing in Table 4.8 and equation 2.30 is defined as:

$$E_{ij} = \frac{\partial \ell n Y_i}{\partial \ell n P_j} = S_j \sigma_{ij}$$

As shown by the above definition, the cross-price elasticity is a function of the elasticity of substitution weighted by the factor share. Since we know all of the factor shares are less than one and positive in value, we can see that all of the information contained in the cross-price elasticity is also contained in the elasticity of substitution. Therefore, it would be redundant to discuss the underlying structure again. However, there are two points that should be noted. First, because the tenured faculty receive almost 60 percent of the total costs (see Chapter III), we see that they are least affected by changes in the prices of the other two inputs (E_{TN} = .109 and E_{TA} = .048). It is reasonable to assume that, when the relative prices of the inputs change, the employment of the tenured faculty will change least.

Second, since the non-tenured faculty were found to be fairly easy substitutes for both the tenured faculty and graduate assistants, the non-tenured would be more susceptible to changes in employment due to changes in relative prices.

The Joint Cost Function -- The Outputs

The joint translog cost function described in equation (2.16) does not differentiate between inputs and outputs within its structure. Thus, it is only a mechanical procedure for adapting the definitions used in determining the input elasticities to the outputs. Table 4.8 reports each of the output elasticities as they have been defined in Chapter II, evaluated at the means of the input variables.

A major difficulty is that of trying to gain a practical understanding of the inverse of the elasticity of substitution as it relates to the process of higher education.[4] This term is defined as the percentage change that will occur in relative shadow output prices based on percentage relative change in the output quantities produced. This definition implies that a university administrator, dean, or chairperson adjusts the price of the output to be supplied

[4] The inverse elasticity of substitution can be made more understandable if we divide it into one. This will change the estimates into the more familiar elasticity of substitution. We should note that there is no true economic meaning to these transformed elasticities, since they imply output prices as exogeneous which, in this case, is not an assumption of the model.

based on the quantity required as determined by perfectly inelastic demand for the output. This simply is not the case and, in fact, presents a serious problem in attempting to draw conclusions, especially conclusions about the relative value of the outputs. This is not to say the inverse elasticities of substitution are important. Table 4.9 shows that undergraduate instruction and research are the most easily substitutable (π_{UR} = .188). They are followed by graduate SCH and research (π_{GR} = .696) and least but, nevertheless, still highly substitutable are graduate and undergraduate SCH (π_{UG} = .779).

It is somewhat surprising that undergraduate instruction and research are the easiest substitutes. However, it does have an understandable interpretation. We would have assumed graduate and undergraduate instruction to have the highest estimate of the elasticity of substitution because the non-tenured and tenured faculty share in the teaching responsibilities of both levels. This ease of substitution does not seem to be present in the data because the non-tenured faculty were more easily substituted for the graduate assistants than they were for the tenured faculty. On the other hand, we can believe that the graduate assistants can be reassigned quite easily between teaching and research. It is apparent, therefore, that the cause of the low estimate of π_{UR} (and strong substitution) is due to the ease with which graduate assistants can be reassigned. The two remaining elasticities of substitution involving graduate

Table 4.9: Joint cost function: Estimates of output elasticities, 1977-78 data.

Part A. Inverse Output Elasticities of Substitution

$\pi_{UU} = -\ .62$	$\pi_{UG} = .779$
$\pi_{GG} = -2.28$	$\pi_{UR} = .188$
$\pi_{RR} = -\ .71$	$\pi_{GR} = .696$

Part B. Marginal Cost Elasticities

$B_{UU} = -.257$

$B_{GG} = -.468$

$B_{RR} = -.267$

Part C. Inverse Output Cross Price Elasticities

$B_{GR} = .30$	$B_{GU} = .323$	$B_{RU} = .078$
$B_{RG} = .16$	$B_{UG} = .16$	$B_{UR} = .071$

NOTE: These elasticities are derived from the coefficients estimated from the share equation (2.18 and 2.20).

instruction (π_{GR} = .696 and π_{UG} = .779) are roughly equivalent. Their values indicate that graduate instruction is easily substitutable for either research or undergraduate instruction. This implies that the tenured and non-tenured faculty can also be easily reassigned since we have assumed that graduate assistants do not contribute to graduate instruction and, therefore, are not included in these estimates.

The estimates of the marginal cost elasticities[5] provide results that do follow closely with what would be expected to occur in higher education and the results of the direct demand analysis. The marginal cost elasticities for all three outputs are negative. These results imply increasing returns to scale. The greatest economies are related to graduate instruction (B_{GG} = -.47). This would indicate that, by increasing the quantities of the outputs by some equal percentage, the greatest decrease in price will be associated with graduate SCH. This result is due primarily to the ease with which both undergraduate instruction and research can be substituted for graduate instruction. Thus, a slight increase in quantity will be accompanied by shifting the faculty away from either research or undergraduate instruction.

It is somewhat surprising that undergraduate instruction (B_{UU} = -.26) does not have the greatest returns to scale as

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[5] The marginal cost elasticity can also be considered to be the inverse of the supply elasticity.

estimated in the direct demand analysis. Comparing the estimates from the direct demand analysis and the joint cost function analysis, we find conflicting results. Recall that in the direct demand analysis undergraduate instruction had the least effect on employment and greatest returns to scale while in the joint product cost function, graduate instruction has the greatest scale economies. If outputs can be increased with less than proportional increases in total employment, we can assume that the underlying supply curve relating price and quantity of the output is downward sloping. The apparent conflict between which type of instruction has the greatest economies of scale may be explained as a problem related to the aggregation of the data. In certain disciplines, such as Economics, Chemistry, or English literature, there may indeed be large economies of scale in the introductory classes. However, the data within the model represent total undergraduate instruction including many upper level classes that cannot take advantage of televised instruction or large lecture halls. This is due to a lack of sufficient demand for the output or the method of instruction, such as sophisticated laboratory equipment. Thus, when all of the undergraduate student credit hours are aggregated at the departmental level, much of the scale economies within a department's undergraduate program may be lost in the process. It appears that the conflicting estimates are due primarily to the statistical methods of estimating the model rather than something inherent in the structure of higher education. Nevertheless, it remains that based on the estimates of the joint cost function, the greatest economies of scale are attributed to the graduate instruction.

Research is also found to have economies of scale (B_{RR} = -.27) to roughly the same degree as undergraduate instruction. This could be explained as synergistic effect within the faculty. As the size of the departments increase, there is also an increase in the professional interaction of the faculty within a department. The increased interaction will increase the possibility for individuals with the same areas of expertise to collaborate. It is from this collaboration that the ideas are developed which ultimately lead to research projects.

The inverse cross-price elasticities of the outputs add significantly to the analysis since they are only the inverse elasticities of substitution weighted by the output share. The implications have been discussed above and it would be redundant to state them again.

Conclusions

Based on a synthesis of the estimates derived from the direct demand analysis and the joint cost function analysis, the following conclusions will be restated. Obviously, this is a rather heavy-handed approach, but is necessary to narrow the focus of discussion from which the policy implications will be drawn.

First, the demand function for tenured faculty, non-tenured faculty, and graduate assistants, are all inelastic and negatively sloped. Second, there is little or no substitution between tenured faculty and graduate assistants, while graduate assistants are easily substitutable with the non-tenured faculty. Also, the tenured and non-tenured faculty are only moderately substitutable for each other. These conclusions are drawn primarily from the joint cost function analysis with some, but not complete, agreement with the results of the direct demand analysis.

On the output side, it appears that there is considerable agreement between both methods. There is strong evidence of increasing returns to scale. The marginal cost elasticities of the outputs are slightly negative, which implies a downward sloping, long-run supply curve. This is corroborated by the output coefficients in the direct demand analysis.

CHAPTER V

MODEL SIMULATIONS

Introduction

We can apply the estimates derived from the two models to some of the major issues currently facing administrators in institutions of higher education. The period of the 1980's is expected to be one of substantial change in how colleges and universities provide services to the society as a whole and individual students in particular. Among the issues that will cause serious difficulties to higher education are the projected decline in the available pool of college-age men and women and the continued reduction in the financial support for higher education by state government. In 1970, higher education received 17.0 percent of the State of Michigan's general fund budget. State support has declined steadily from that time to the point where less than 14 percent of the State's general fund budget supports higher education. A continued decline has implications for future fiscal planning. While the simulations presented in this chapter cannot eliminate all of the uncertainty of the future, they might shed some light on an area that has previously been unexplored.

The conclusions of the following sections are based only on the 1977-78 data because the estimated cost function was well-behaved for only that year. In addition, the estimated coefficients are evaluated only at the means of the independent variables. Thus, if a department has unusually low research output (like Family and Child Sciences, for example) the analysis will indicate substitutions of the inputs that may not be applicable.

It is possible that many institutions of higher education will be faced with non-marginal changes that cannot be estimated within the context of this model. This is because we have assumed a fixed structure to the production process. The decline in enrollments could be so significant that some administrators would be forced to restructure their institutions more than just beyond the slight changes to the level of employment of the academic labor services as suggested by the estimates of this model. The restructuring could include eliminating certain degree programs, consolidating departments or colleges, or closing the institution entirely.

Declining Undergraduate Enrollments

The most crucial issue of the next decade confronting higher education is how a university can maintain the quality of its product during a period of declining enrollments and revenues. Although measures of quality are not directly included in this study, a university that cannot adjust its faculty to meet the needs of the future will find itself more concerned with survival rather than maintaining quality.

Naturally, the effects of declining enrollments will not be equally felt across all colleges and universities. The forecasted decline can be considered within the context of this study with two possible policy alternatives available to administrators. First, there is the possibility of maintaining salaries and letting the reduction in undergraduate instruction lead to a reduction in the number of faculty and graduate assistants employed. Second, there may be a desire not to decrease employment but to simply produce more of another output, namely research. Each of these two possibilities can be analyzed within the framework of the direct demand analysis.[1] The predicted changes determined from this model on employment and research are not meant to be _de facto_ changes that would occur at all institutions but only provide some additional information for determining employment policies.

The implications of the first alternative can be found by simply reading the coefficients on the undergraduate instruction variable, Y_U, from each of the three demand equations (see Table 4.3). Each coefficient tells us the percentage change employment that would occur from a percentage change in undergraduate instruction. Thus, we find a 10 percent decline in Y_U will cause: i) the demand for the tenured faculty to fall by 1.6 percent, ii) the demand for the non-tenured faculty to decline by 1.1 percent, and iii) the

[1] The constraints of homogeneity and symmetry are imposed for the year 1977-78 only.

demand for graduate assistants to decrease by .5%. These results suggest that graduate assistants would be least affected by a teaching cutback. We intuitively know just the opposite would probably occur, in the short run. This is because less teaching would reduce the size of classes and the number of sections taught for each course. Almost certainly, we would find that the number of graduate assistants needed would rapidly decrease while, at least temporarily, the demand for the faculty would remain unchanged. However, from a long run perspective these results are reasonable. They suggest that the faculty, both tenured and non-tenured, would have a decline in the demand for their services as departments reduce their faculty in an attempt to gain flexibility. They would then permit the number of graduate assistants to fluctuate only on a short run basis filling temporary openings.

The second alternative assumes that the demand for each type of labor service is unchanged and the faculty and graduate assistants devote more time to research as teaching loads are reduced due to a lack of students. Although it is not precisely correct to say that the decline in instruction <u>caused</u> an increase in research, we can look at the two relevant coefficients (Y_U and Y_R) as offsetting one another to maintain the level of factor demand. The calculations necessary can be reduced to a simple ratio of the coefficient on Y_U over the coefficient on Y_R to determine the required percentage increase in research.

The relevant values from Table 4.3 are:

Demand Equation	Y_U	Y_R	Ratio (Y_U/Y_R)
Tenured faculty	.16	.33	.48
Non-tenured faculty	.11	.16	.69
Graduate assistants	.05	.68	.07

If undergraduate instruction were to decline 10 percent, a 4.8 percent offsetting increase would be necessary in research publications for the demand of the tenured faculty to remain unchanged. The demand for the non-tenured faculty would remain constant if the department's research were to rise by 6.9 percent, while the demand for graduate assistants would require only a .7 percent increase in research to offset the decline in undergraduate instruction. These results indicate that demand can be maintained for all three labor services with less than a 10 percent increase in research. As discussed in Chapter IV, this is due primarily to changes in research having a significantly greater effect on factor demand than undergraduate instruction. Thus, we see that a small percentage increase in research will offset proportionately larger declines in undergraduate instruction. This is especially true for the demand for graduate assistants when the increase in research would only need to be .7 percent. Because the coefficient on Y_R in the graduate assistant demand equation is 6.8, we can conclude from this coefficient that increasing research output would increase the demand for graduate assistants by a larger percentage than the increase in the demand for either type of faculty. If a department were to shift its academic labor services to the production of research, there would need to be a greater number of graduate assistants assigned to each faculty member than would be required in the production of instruction. The graduate assistants would provide the "legwork" of research such as reviewing the literature or collecting data. It is for this reason that the decline in undergraduate instruction can be easily offset by increasing research to maintain the demand for graduate assistants. The tenured and non-tenured faculty can then become more productive with the reassigning of graduate assistants from instruction to research and, consequently, research must rise by a greater percentage to maintain the level of their demand.

The above estimates indicate that the tenured faculty would have the greatest decrease in demand with graduate assistants having the least. In practice, this would not occur at least in the short run. Administrators would prefer, instead, to first eliminate the graduate assistants up to the point where it becomes detrimental to their graduate programs with a decline in their undergraduate programs. At that point, adjustments, either in salary or demand, would next occur with the non-tenured faculty. The reasons for this are beyond the ability of the model to take into account such as preserving the prestige of the university or the political influence of the tenured faculty in preserving their positions at the expense of the non-tenured faculty and graduate assistants.

Special "Catch-Up" Salary Increases to the Faculty

An issue that is currently confronting many institutions is that of a university finding that the salaries paid its faculty are considerably less than faculty salaries at similar institutions. Michigan State University, for example, is continually ranked near the bottom of the Big Ten in the salaries paid to full professors. In an attempt to correct the situation, the university administrators recently instituted a 2 percent across-the-board salary increase to faculty members. The raise was not given to graduate assistants. We can ask, "How will raising faculty salaries (P_T and P_N) by 2 percent affect the level of demand for all three types of academic labor services?" The joint product cost function estimates will again be used because they provide the more reliable estimates of the cross-price elasticities (as reported in Table 4.8).

It is a trivial matter to determine the impact of the 2 percent salary increase for the faculty after the price and cross-price elasticities have been estimated. With respect to the tenured faculty, we find only a slight decrease in demand of .32 percent (E_{TN} = -.16) due to increasing their salary 2 percent along with an offsetting increase in demand because of the non-tenured faculty also receiving a 2 percent increase (from the cross-price elasticity (E_{TN} = .109)). Thus, the net effect is an extremely small decrease in demand for the tenured faculty of .10 percent. These results indicate that the change in demand for the tenured faculty is negligible which is reasonable since it was not the intention of the administration to reduce demand (or employment) of the faculty but only to offer additional compensation to those currently employed.

The net effect on demand for the non-tenured faculty is more than twice that of the tenured faculty at .29 percent. This is caused by a .88 percent decrease in demand due to the increase in non-tenured faculty salaries (E_{NN} = .44). This is offset by an increase in demand of .59 percent caused by the increase in tenured faculty salaries. These results, although greater than for the tenured faculty, are consistent with the policy of not significantly affecting demand but still providing for salary adjustments. The 2 percent increase may not be sufficiently large to restore salary level to match those of the peer group institutions; however, it does acknowledge an area of deficiency that the administration is attempting to correct.

If we look at the demand for graduate assistants, we see an overall increase of .73 percent. This increase arises from the substitutability of both types of faculty with graduate assistants found in our results. The increase in demand can be divided into two roughly equal shares caused by the salary increases attributed to the tenured and non-tenured faculty. Although the substitution of graduate assistants is greater with the non-tenured faculty than the tenured faculty, the tenured faculty share is much larger. The implications of this are that, although the graduate assistants are more easily substitutable with the non-tenured faculty, the demand for their services is much more sensitive to changes in the salary paid the tenured faculty. This is because the tenured faculty receive a much greater share of total cost which causes large changes in the demand for graduate assistants with only slight changes in the salaries paid the tenured faculty. Nevertheless, the 2 percent salary increase should be considered to have only a minimal effect on the demand for graduate assistants.

The major result of this hypothetical exercise is that the decline in the demand for the non-tenured faculty is more than twice that of the tenured faculty. These results can be explained by the somewhat unexpected estimates of the elasticities of substitution discussed in Chapter IV. Although both types of faculty received the same salary increases, the tenured faculty's contribution to research and graduate instruction was such that neither the non-tenured faculty nor graduate assistants could be easily substituted for them. On the other hand, graduate assistants were estimated to easily substitute for the non-tenured faculty. Therefore, it could be concluded, if the salaries of both types of faculty were to increase by the same amount, the administration would be more willing to reduce the number of non-tenured faculty and increase the number of graduate assistant appointments. Obviously, these results are distorted by the misspecification of the research output.

Increasing Research Outputs

It is not difficult to imagine a situation where the university administration would, in anticipation of declining enrollments, wish to establish a reputation as a research oriented institution. This decision to increase the research productivity of the faculty would help to minimize the potentially disastrous effect of the reduced number of students. Increasing the number of research publications would raise the reputation of the institution and, in turn, make it more competitive in attracting more research grants from both private and governmental sources in future years. This reasoning on the surface, appears to be a viable approach to the future. However, in order to produce more research, the academic labor services must be shifted away from undergraduate and graduate instruction. Thus, the effects of increasing research will cause the relative value of all three outputs to change. The relative changes in the values of the outputs will determine whether the policy of greater research output will be desirable.

The joint product cost function is the only model that provides the necessary inverse cross-price elasticities to analyze the implications of this hypothetical policy. If we assume a 10 percent increase in research this will lower the relative value of research by 2.7% (B_{RR} = 6.267 from Table 4.9). An increase in the quantity supplied at a lower value is due to the increasing returns to scale discussed in Chapter IV. In addition, there will also be an increase in the value of instruction due to the substitutability of the outputs. As more labor services are directed toward producing research, less will be devoted to undergraduate and graduate instruction. Since both types of instruction were also estimated to have increasing returns to scale, we would expect their relative values to rise. In fact, the model estimates that the value of undergraduate instruction would rise .71 percent while a much larger increase would occur in the relative value of graduate instruction at 3.0 percent.

The implication of these results is that graduate assistants, assigned to support the faculty as graders and proctors for large classes, would be reassigned to faculty research projects. This would cause the departments to reduce their average class size and offer more sections. This would make the relative value of undergraduate instruction rise. However, we estimated the rise in graduate instruction to be more than three times that of undergraduate instruction. Therefore, the faculty providing graduate instruction would be reassigned to undergraduate instruction to restore the lost scale economies. Thus, the relative value of graduate instruction rises because there are fewer teaching faculty in graduate instruction. The relative value of research falls because there are more graduate assistants providing support such as data collection and reviewing the literature for the research oriented faculty.

Although this story is plausible and provides an explanation to the estimates, there are other possibilities that are just as plausible. The tenured and non-tenured faculty could be reassigned to research and away from undergraduate instruction while graduate assistants could be used more in undergraduate instruction without supervision. This would raise the price of undergraduate instruction because more sections with fewer students in each section would be needed which agrees with our results. With more faculty members devoting their time to research, there would be a synergistic effect that would generate more ideas and, hopefully, more publications while reducing the value of each research unit. The graduate program would also have a reduction in its teaching faculty. This would, in many instances, require the closing of sections and the curtailing of course offerings and, in turn, raise the relative value of the output. Another possible method of transferring the labor services from instruction to research would be to simply move the tenured and non-tenured faculty and graduate assistants in the same proportion that they exist within the current teaching structure. For example, if there are four graduate assistants for every faculty member teaching an undergraduate course, then reassigning that faculty member to research would also imply reassigning the four graduate assistants to research activities. The graduate teaching faculty members that do not have graduate assistants assigned to them would also be assigned to research without any corresponding transfer of graduate assistants. Thus, there would be a larger increase in the price of graduate instruction because every individual transferred would require increasing substantially the workload burden of the remaining graduate teaching faculty. Undergraduate instruction would have much less of a price increase because the workload increase would be spread among the graduate assistants having to grade more papers or proctor larger classes. The faculty members transferred to research would be able to enjoy the same efficiency they had when teaching because their graduate assistants would still provide support for their research activities.

Regardless of which method is used to increase the number of research publications of the department, we would find that the largest price increase would be for graduate instruction. The increase in relative value of undergraduate instruction at .7 percent is negligible.

CHAPTER VI

POLICY IMPLICATIONS AND CONCLUSIONS

Overall Perspective of Analysis

In Chapter I, we stated that this study was motivated by an impending decline in higher education enrollments. Therefore, the implications for higher education administrative policy should only be considered within the context of declining enrollments. The nation's colleges and universities have shown themselves to be quite capable of administering increasing enrollments, as seen by the rapid expansion in higher education in the 1960's, but it is far more difficult to retrench and cut back inputs than it is to grow.

Before the policy implications of this study can be developed, a very important distinction must be made. One of the inputs of the academic labor service was classified as "non-tenured faculty." This input, in actuality, consists of two inputs. One group is temporary faculty, or those individuals who are appointed only on a year-to-year basis, and the other is those faculty members who are in the "tenure stream" but who do not yet have continuing tenure. This distinction between temporary and tenure stream appointments of the non-tenured faculty is an important option available to administrators. Thus, in order to relate the conclusions of this study to administrative policy, it will be stated whether a change should occur through changes in the number of temporary or tenure stream appointments. In addition, there are several institutional constraints that also affect administrative policy and should be explicitly stated. One option available to reduce the number of tenured faculty is through programs and policies affecting the supply side of the market such as offering sizable cash bonuses for early retirement. In this analysis, we concluded that, for the most part, policies directed at the demand for tenured faculty would have little effect on substantially reducing employment. This is because of the inelastic demand for the tenured faculty in the joint product cost function. Thus, normal attrition will be the only factor causing the number of tenured faculty to decline.

It can be imagined that an administrator, faced with projection of a sharp downturn in enrollment, might take a very conservative approach in setting employment policies for the faculty and graduate assistants. As stated in Chapter I, it was previously assumed without the benefit of the conclusions of this study that the tenured and non-tenured faculty would be easy substitutes. In addition, we assumed that graduate assistants were substitutes with both types of faculty. Given these assumptions, an administrator would want to minimize his future employment and financial obligations and keep as much budget flexibility as possible. This reasoning would lead him to conclude the best policy would be one of replacing all tenured faculty positions with temporary faculty or graduate assistants. Thus, when a faculty member retires or resigns, his or her replacement would be hired on a temporary year-to-year basis as either a non-tenured faculty member or graduate assistant.

Based on the results presented in this study, this would not be the most productive cost-minimizing policy to follow. First, we showed that graduate assistants are easy substitutes with the non-tenured faculty and weak substitutes with the tenured faculty. Also, the non-tenured faculty and tenured faculty were found to be substitutes but much less than was expected. These results (ignoring misspecification of the variables) imply that the tenured faculty cannot be easily replaced by the temporary faculty on a one-for-one basis without affecting the ability of the departments to produce their outputs. Instead, it would be better to maintain the number of faculty positions and reduce the number of non-tenured faculty. The decline in non-tenured employment could then be offset by increasing the number of graduate assistantships. The concern for maintaining flexible budgetary obligations would be substantially reduced because of the ease with which departments could make adjustments to the number of graduate assistants they have employed. It may be necessary, if student enrollments decline drastically, to reduce employment in all three types of labor services. However, based on the estimates of this study, the non-tenured faculty should have the greatest percentage decrease in employment.

The reasons for maintaining the tenured and tenure stream faculty while decreasing the temporary faculty are quite plausible despite the misspecification of the model variables. Recall that there were increasing returns to scale for all outputs with research being an easy substitute with graduate and undergraduate instruction. In addition, it is assumed that most of the research is produced by the tenured or tenure stream faculty with the temporary faculty mostly involved in undergraduate instruction. If undergraduate enrollments are reduced by, say, 15 percent then total employment of the academic labor services devoted to undergraduate instruction must be reduced by more than 15 percent. The tenured and tenure stream faculty could be easily shifted away from instruction and into research. The temporary faculty would be reduced with graduate assistants providing the necessary support to fill temporary shortages that would then consist of mostly those individuals who are in the tenure stream. This policy would not affect the ability of the university to attract quality individuals since being hired would, to some degree, be an offer of tenure at some time in the future.

There is an additional advantage to this general employment policy that deserves special consideration. The continued support of graduate assistantships will benefit the department by maintaining the graduate instruction program. From the direct demand analysis, we stated there was a strong correlation between the size of the graduate program and the number of graduate assistants employed. By reducing the size of the temporary faculty and replacing them with graduate assistants, the department will also be supporting its graduate program and maintaining the teaching loads of the graduate teaching faculty. If the departments were forced to eliminate graduate assistant appointments this would certainly cause graduate enrollments to decline which, in turn, would reduce the demand for the services of the tenured and tenure stream faculty. It is this correlation of the number of graduate assistants employed affecting the level of demand for the other labor services through generating student credit hours.

Future Research

There are four areas in this study that would add considerably to our understanding of the academic labor markets of higher education. As stated in Chapter III, very little research has been done in this area and the list below is not intended to be all-inclusive. It is, however, necessary to focus upon those areas of this study where the underlying assumptions, although necessary, may not be applicable.

First, it would be useful to gain an understanding of the process of how instructional departments adjust their mix of labor services to reach their optimal level. This study assumed that all departments were operating at their most efficient level through their ability to adjust all inputs instantaneously. Some study was done with the direct demand analysis model using only a three year lag period. However, this was inadequate to fully explain the process of the changing demand for tenured and non-tenured faculty caused by exogenous changes in the level of the outputs. Knowing the rate at which departments adjust their labor services would be a valuable tool in setting policy. Departments that are experiencing large changes in enrollments would then have guidelines to follow in making the transition to a new level of output demand.

The second area of further study should involve questioning whether the instructional departments actually do operate at their optimal level. This would require designing a methodology that determines the true production possibilities frontier and tests whether a unit is operating at that level. The study of optimality also would involve defining the appropriate general functional form of production. The translog cost function was adapted to meet the purposes of this study. This is not the only possible production function that can be applied to joint product processes. Further investigation could involve use of other general functions that might be more appropriate than the translog.

Third, a major obstacle to drawing meaningful conclusions from the estimates of the elasticities was the misspecification of the research output. Since this is the first study to treat research publication as an output, it does add to better identifying the process of higher education but must be improved to be useful. The highly cyclical nature of research and the long time periods involved from beginning to end were not adequately dealt with by using only two years of data. Using more years pooled across all departments might improve the model's ability to estimate a well-behaved cost function (if, in fact, a well-behaved cost function exists). It may be appropriate to include other types of professional accomplishments within the variable research. Rather than just refereed journal articles and books, delivered paper or non-refereed articles could also be included since they do represent an investment of time on the part of the faculty.

Fourth, we believe some of the estimates of the input elasticities of substitution were affected by defining the non-tenured faculty to include tenure stream and temporary faculty. It would be useful to know if the model presented here would provide different estimates if the three types of academic labor services were defined as i) tenured and tenure stream faculty, ii) temporary faculty, and iii) graduate assistants. It is possible that the estimated cost function may be well-behaved and meet the first- and second-order conditions satisfactorily when the inputs are defined in this form.

This study was designed for the purpose of identifying the substitutions of academic labor services within the context of a general joint product cost function. It has fulfilled that goal although it appears to have raised more questions regarding the structure of higher education than it answered. Nevertheless, it does provide an initial understanding of how faculty and graduate assistants combine to produce the outputs of instruction and research.

APPENDICES

APPENDIX A

LIST OF DEPARTMENTS INCLUDED AND DELETED FROM THE DATA

	1977-78	1978-79
Agriculture and Natural Resources		
Agricultural Economics	x	x
Agricultural Engineering	x	x
Animal Husbandry	x	x
Crop and Soil Science	x	x
Dairy Science	x	x
Fisheries & Wildlife	x	x
Forestry	x	x
Horticulture	x	x
Packaging	x	x
Poultry Sciences	x	x
Parks & Recreation Resources	x	x
Resource Development	x	x
Arts and Letters		
English Language Center	D	x
Art	C	C
English	x	x
German & Russian Languages		
Linguistics, Oriental and African Languages	x	x
Romance Languages	x	x
History	x	x'
Music	C	C
Philosophy	x	x
Religious Studies	C	C
Theatre	C	C
Business		
Accounting & Financial Administration	x	x
Business Law and Office Administration	x	x
Economics	x	x
Hotel Management	x	x
Management	x	x
Marketing and Transportation Administration	x	x

	1977-78	1978-79
Communication Arts & Sciences		
Advertising	x	x
Audiology & Speech Science	x	x
Communication	x	x
Journalism	x	x
Telecommunication	x	x
Education		
Administration & Higher Education	A	A
Counseling & Personnel Services	A	A
Elementary & Special Education	A	A
Secondary Education	A	A
Student Teaching	A	A
Health and Physical Recreation	A	A
Engineering		
Chemical Engineering	x	x
Civil & Sanitary Engineering	x	x
Electrical Engineering and Systems Science	x	x
Computer Science	x	x
Mechanical Engineering	x	x
Metallurgy, Mechanical and Materials Science	x	x
Human Ecology		
Human Nutrition & Foods	x	x
Family and Child Science	x	x
Family Ecology	x	x
Human Environment and Design	x	x
Natural Science		
Astronomy	x	D
Biochemistry	x	x
Biophysics	x	x
Botany and Plant Pathology	x	x
Chemistry	x	x
Entomology	x	x
Geology	x	x
Mathematics	x	x
Microbiology and Public Health	C	C
Nursing	C	C
Physiology	C	C
Physics	x	x
Statistics	x	x
Zoology	x	x

	1977-78	1978-79
Social Science		
Labor and Industrial Relations	B	B
Anthropology	x	x
Geography	x	x
Criminal Justice	x	x
Political Science	x	x
Psychology	x	x
Social Work	x	x
Sociology	x	x
Urban Planning & Landscape Architecture	x	x
University College		
American Thought and Language	D	D
Humanities	D	D
Natural Science	D	D
Social Science	D	D
Justin Morrill	D	D
James Madison	x	x
Lyman Briggs	D	x
Urban Development		
Racial and Ethnic Studies	D	D
Urban and Metropolitan Studies	x	x
Human Medicine	C	C
Osteopathic Medicine	C	C
Veterinary Medicine	C	C

KEY:

x = Department included in the sample.
A = Non-traditional departments; data cannot be assigned to department directly.
B = Public service is major output.
C = Clinical departments where research cannot be defined in terms of books and journal articles.
D = One output or input is zero.

APPENDIX B

MODEL DATA

1978-79	Output Quantities: Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
College of Agriculture and Natural Resources			
Agricultural Economics	5632	2717	46
Agricultural Engineering	7520	921	50
Animal Husbandry	5682	1090	92
Crop and Soil Science	12489	1855	159
Dairy Science	4214	877	77
Fisheries & Wildlife	5943	1376	18
Forestry	7384	1078	39
Horticulture	10236	1171	118
Packaging	5711	251	1
Parks & Recreation	8908	777	8
Poultry Sciences	1646	325	27
Resource Development	3815	1484	21
Arts and Letters			
English	31296	2223	48
English Language Center	4530	105	1
German & Russian	7641	292	8
History	26429	1350	50
Linguistics, Oriental and African Languages	2759	444	15
Philosophy	12157	738	10
Romance & Classical Languages	23622	565	47
College of Lyman Briggs	13997	5	3

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Business			
Accounting & Financial Administration	48046	4543	27
Business Law & Office Administration	12453	417	9
Economics	58124	4312	63
Hotel, Restaurant & Institution Management	12567	252	15
Management	23712	5541	15
Marketing	29328	3633	28
Communication Arts			
Advertising	13305	587	17
Audiology & Speech	5503	1517	7
Communications	27917	2443	35
Journalism	8601	519	9
Telecommunication	8596	978	11
Engineering			
Chemical Engineering	6057	759	7
Civil Engineering	9876	1168	8
Computer Science	20611	766	7
Electrical Engineering	11775	2101	26
Mechanical Engineering	11789	703	22
Metallurgy, Mechanical and Materials Science	10589	501	12

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Human Ecology			
Family and Child Science	7222	1431	2
Family Ecology	4644	726	13
Food Science	13897	1948	98
Human Environment	17285	453	6
College of James Madison	12544	48	3
Natural Science			
Astronomy & Astrology	3256	31	9
Biochemistry	8642	4976	114
Biophysics	444	566	13
Botony & Plant Pathology	7922	1822	103
Chemistry	53432	4945	105
Entomology	3459	1063	60
Geology	6147	894	21
Mathematics	102781	2668	54
Nursing	9280	303	8
Physics	26885	1801	173
Statistics & Probability	13200	1515	18
Zoology	12123	1461	33
Social Science			
Anthropology	12427	1245	17
Criminal Justice	16538	2037	14
Geography	14052	1046	27
Political Science	28033	2062	38
Psychology	61065	6796	65
Social Work	7188	5283	3

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Social Science (continued)			
Sociology	18079	3798	29
Urban Planning	8005	890	8
College of Urban Development			
Urban & Metropolitan Studies	4322	75	18
1977-78			
College of Agriculture and Natural Resources			
Agricultural Economics	5785	2321	17
Agricultural Engineering	7622	777	25
Animal Husbandry	6496	691	42
Crop and Soil Science	4466	1902	42
Dairy Science	4724	690	57
Fisheries & Wildlife	7764	1141	17
Forestry	8061	810	20
Horticulture	9323	1172	42
Packaging	4608	87	1
Parks & Recreation	8777	777	6
Poultry Sciences	2309	316	9
Resource Development	4163	1652	12
Arts and Letters			
English	34310	2445	81
German & Russian	8322	322	11

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Arts and Letters (continued)			
History	26749	1366	20
Linguistics, Oriental and African Languages	2771	364	5
Philosophy	11827	630	8
Romance & Classical Languages	24077	594	27
Business			
Accounting & Financial Administration	49255	4472	14
Business Law & Office Administration	11828	445	6
Economics	55902	4552	64
Hotel, Restaurant & Institution Management	14173	340	9
Management	24713	7057	22
Marketing	26886	4112	32
Communication Arts			
Advertising	12801	846	6
Audiology & Speech	6134	2066	7
Communications	24222	2643	33
Journalism	7980	680	3
Telecommunication	7979	845	6
Engineering			
Chemical Engineering	5201	579	10
Civil Engineering	9652	1038	12

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Engineering (continued)			
Computer Science	18806	537	6
Electrical Engineering	10550	2236	29
Mechanical Engineering	9473	784	15
Metallurgy, Mechanical and Materials Science	7078	530	9
Human Ecology			
Family and Child Science	7460	1492	5
Family Ecology	4991	896	5
Food Science	14391	2106	110
Human Environment	17910	250	7
Natural Science			
Biochemistry	7920	3230	74
Biophysics	179	391	20
Botony & Plant Pathology	7794	1710	66
Chemistry	52065	5872	125
Entomology	4803	929	67
Geology	6319	822	21
Mathematics	101178	2741	66
Nursing	7310	321	1
Physics	26685	1843	202
Statistics & Probability	16924	1119	16
Zoology	15151	1754	25

	Output Quantities		
	Undergraduate Instruction (Y_U)	Graduate Instruction (Y_G)	Research (Y_R)
Social Science			
Anthropology	12621	1215	14
Criminal Justice	17553	1702	22
Geography	13718	2620	29
Political Science	29897	1330	48
Psychology	62120	1993	126
Social Work	7344	6837	14
Sociology	18103	4559	24
Urban Planning	9218	1131	6
College of Urban Development			
Urban & Metropolitan Studies	3421	27	12

1978-79	Input Prices: Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
College of Agriculture and Natural Resources			
Agricultural Economics	26933	19421	9522
Agricultural Engineering	27711	15473	11408
Animal Husbandry	27348	16378	9686
Crop and Soil Science	26969	14391	10496
Dairy Science	24555	17488	9128
Fisheries & Wildlife	25861	17298	9830
Forestry	27135	18018	9218
Horticulture	25684	17008	9224
Packaging	26173	20416	8820
Parks & Recreation	25105	18723	9360
Poultry Sciences	26582	16051	9172
Resource Development	26340	15913	9364
Arts and Letters			
English	24744	12299	9332
English Language Center	19558	12003	9270
German & Russian	22564	14191	9418
History	24328	15687	9468
Linguistics, Oriental and African Languages	21580	14150	9140
Philosophy	23457	14290	9442
Romance & Classical Languages	23398	12891	9184
College of Lyman Briggs	23370	11175	10066

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Business			
Accounting & Financial Administration	29133	22091	9956
Business Law & Office Administration	27870	19900	9246
Economics	32092	18738	9790
Hotel, Restaurant & Institution Management	29662	19272	9066
Management	28506	22430	9674
Marketing	33173	21285	9790
Communication Arts			
Advertising	30500	18741	9466
Audiology & Speech	27527	14894	8956
Communications	25611	16714	9856
Journalism	23636	14160	9802
Telecommunication	26862	14222	8696
Engineering			
Chemical Engineering	29127	19945	10556
Civil Engineering	28001	19472	10380
Computer Science	27119	19775	10742
Electrical Engineering	25574	16958	10644
Mechanical Engineering	27740	17671	10314
Metallurgy, Mechanical and Materials Science	25313	18411	10672

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Human Ecology			
Family and Child Science	24389	15542	9200
Family Ecology	24539	16014	9122
Food Science	25235	15415	9214
Human Environment	21417	14229	9432
College of James Madison	20202	13896	6018
Natural Science			
Astronomy & Astrology	27955	18970	9630
Biochemistry	29583	14894	8583
Biophysics	26858	10496	9307
Botony & Plant Pathology	26167	13737	9192
Chemistry	29783	16655	10120
Entomology	24510	15800	9910
Geology	26279	16163	8990
Mathematics	25447	15066	10092
Nursing	20968	17052	12390
Physics	28620	15097	9610
Statistics & Probability	26760	17721	9728
Zoology	26167	16578	9188
Social Science			
Anthropology	25484	15727	10996
Criminal Justice	27946	17647	8846
Geography	26789	13855	9048
Political Science	26337	14378	9338
Psychology	27300	15553	9014
Social Work	25031	16136	9048

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Social Science (continued)			
Sociology	26890	14892	9634
Urban Planning	26354	16781	8102
College of Urban Development			
Urban & Metropolitan Studies	23761	15739	10792
1977-78			
College of Agriculture and Natural Resources			
Agricultural Economics	25051	17310	8876
Agricultural Engineering	23733	18483	9912
Animal Husbandry	25402	16388	9012
Crop and Soil Science	25486	14354	9496
Dairy Science	24625	15585	8618
Fisheries & Wildlife	23895	15200	8860
Forestry	24323	16305	8630
Horticulture	24007	14968	8618
Packaging	26623	17000	7896
Parks & Recreation	23063	18762	8510
Poultry Sciences	24623	14413	8698
Resource Development	24501	13053	8844
Arts and Letters			
English	23219	13007	8908
German & Russian	20433	14550	8434

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Arts and Letters (continued)			
History	22948	14145	8906
Linguistics, Oriental and African Languages	20522	16650	8060
Philosophy	21622	14792	8800
Romance & Classical Languages	22489	13512	8454
Business			
Accounting & Financial Administration	27893	20157	8822
Business Law & Office Administration	26220	18800	9360
Economics	29500	18587	8792
Hotel, Restaurant & Institution Management	27795	16780	8540
Management	27578	20287	9178
Marketing	30844	17862	9828
Communication Arts			
Advertising	23858	16537	8422
Audiology & Speech	28271	13786	8132
Communications	24798	15203	10166
Journalism	22530	16957	9046
Telecommunication	23940	14166	8180
Engineering			
Chemical Engineering	26021	19050	9708
Civil Engineering	26149	17320	9606

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Engineering (continued)			
Computer Science	24619	18396	10330
Electrical Engineering	23765	17375	9892
Mechanical Engineering	26244	16487	10050
Metallurgy, Mechanical and Materials Science	26160	18083	9892
Human Ecology			
Family and Child Science	22690	15140	8248
Family Ecology	23895	15200	8366
Food Science	23993	16722	8614
Human Environment	21184	14428	8704
Natural Science			
Biochemistry	27448	12904	8944
Biophysics	27815	11605	8774
Botony & Plant Pathology	23860	10059	8628
Chemistry	27125	12449	9610
Entomology	22814	15177	9244
Geology	24892	16650	8236
Mathematics	24066	13547	9532
Nursing	19158	15913	12114
Physics	27066	14466	8850
Statistics & Probability	25856	16556	9380
Zoology	24193	13772	8544

	Input Prices		
	Tenured Faculty Avg. Salary (P_T)	Non-Tenured Faculty Avg. Salary (P_N)	Graduate Assistants Avg. Salary (P_A)
Social Science			
Anthropology	23935	15979	8829
Criminal Justice	26424	17644	8690
Geography	25605	13487	8624
Political Science	24872	13824	8510
Psychology	25730	15628	8676
Social Work	24022	14451	8200
Sociology	24984	16587	8702
Urban Planning	25463	17746	8556
College of Urban Development			
Urban & Metropolitan Studies	22567	15488	9518

1978-79	Output Shares: Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
College of Agriculture and Natural Resources			
Agricultural Economics	.051000	.140928	.808000
Agricultural Engineering	.229000	.213526	.557000
Animal Husbandry	.296192	.119808	.584000
Crop and Soil Science	.116339	.250661	.633000
Dairy Science	.077000	.121191	.801000
Fisheries & Wildlife	.161550	.288450	.550000
Forestry	.090312	.227688	.682000
Horticulture	.191142	.095858	.713000
Packaging	.540568	.247432	.212000
Parks & Recreation	.256410	.238590	.505000
Poultry Sciences	.269240	.238760	.492000
Resource Development	.079689	.223311	.697000
Arts and Letters			
English	.715040	.156960	.128000
English Language Center	.805086	.112914	.082000
German & Russian	.686424	.201576	.112000
History	.500050	.184950	.315000
Linguistics, Oriental and African Languages	.590272	.211728	.198000
Philosophy	.568320	.171680	.260000
Romance & Classical Languages	.728456	.122544	.149000
College of Lyman Briggs	.787630	.002000	.210000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Business			
Accounting & Financial Administration	.492462	.260538	.247000
Business Law & Office Administration	.692676	.120324	.187000
Economics	.411203	.261797	.327000
Hotel, Restaurant & Institution Management	.725845	.085155	.189000
Management	.393666	.327334	.279000
Marketing	.449394	.276606	.274000
Communication Arts			
Advertising	.680448	.205552	.114000
Audiology & Speech	.344187	.342813	.313000
Communications	.406000	.174000	.420000
Journalism	.681676	.201324	.117000
Telecommunication	.469836	.372164	.158000
Engineering			
Chemical Engineering	.480246	.305754	.214000
Civil Engineering	.413478	.288522	.298000
Computer Science	.524900	.199100	.276000
Electrical Engineering	.402318	.318682	.279000
Mechanical Engineering	.541835	.249165	.209000
Metallurgy, Mechanical and Materials Science	.472668	.189332	.338000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Human Ecology			
Family and Child Science	.317107	.305892	.377000
Family Ecology	.298680	.487320	.214000
Food Science	.205524	.091476	.703000
Human Environment	.414739	.108261	.477000
College of James Madison	.683848	.134152	.182000
Natural Science			
Astronomy & Astrology	.037840	.134160	.828000
Biochemistry	.032850	.117150	.850000
Biophysics	.151984	.216016	.632000
Botony & Plant Pathology	.374745	.270255	.355000
Chemistry	.114125	.160875	.725000
Entomology	.400867	.266133	.333000
Geology	.651406	.130594	.218000
Mathematics	.737038	.064962	.198000
Nursing	.239080	.190920	.570000
Physics	.438100	.235900	.326000
Statistics & Probability	.298528	.309472	.392000
Zoology	.369342	.208658	.422000
Social Science			
Anthropology	.362340	.308660	.329000
Criminal Justice	.453007	.285993	.261000
Geography	.430787	.122213	.447000
Political Science	.332664	.331336	.336000
Psychology	.366858	.434142	.199000
Social Work	.250978	.386002	.363000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Social Science (continued)			
Sociology	.571540	.248460	.180000
Urban Planning	.497216	.046784	.456000
College of Urban Development			
Urban & Metropolitan Studies	.074002	.152998	.773000
1977-78			
College of Agriculture and Natural Resources			
Agricultural Economics	.253440	.274560	.472000
Agricultural Engineering	.282464	.133536	.584000
Animal Husbandry	.142396	.224604	.633000
Crop and Soil Science	.058035	.160965	.781000
Dairy Science	.177546	.288454	.534000
Fisheries & Wildlife	.092538	.225462	.682000
Forestry	.204344	.082656	.713000
Horticulture	.692652	.095348	.212000
Packaging	.425700	.069300	.505000
Parks & Recreation	.213868	.294132	.492000
Poultry Sciences	.110595	.192405	.697000
Resource Development	.708936	.163064	.128000
Arts and Letters			
English	.655344	.232656	.112000
German & Russian	.521285	.163715	.315000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Arts and Letters (continued)			
History	.615936	.186064	.198000
Linguistics, Oriental and African Languages	.592000	.148000	.260000
Philosophy	.759980	.030020	.210000
Romance & Classical Languages	.748880	.102120	.149000
Business			
Accounting & Financial Administration	.431469	.321531	.247000
Business Law & Office Administration	.669099	.143901	.187000
Economics	.476484	.196516	.327000
Hotel, Restaurant & Institution Management	.759907	.051093	.189000
Management	.397992	.323008	.279000
Marketing	.468996	.257004	.274000
Communication Arts			
Advertising	.631718	.254282	.114000
Audiology & Speech	.375102	.311898	.313000
Communications	.403100	.176900	.420000
Journalism	.733773	.149227	.117000
Telecommunication	.470678	.371332	.158000
Engineering			
Chemical Engineering	.416580	.369420	.214000
Civil Engineering	.475956	.226044	.298000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Engineering (continued)			
Computer Science	.518384	.205616	.276000
Electrical Engineering	.502537	.218463	.279000
Mechanical Engineering	.588504	.202496	.209000
Metallurgy, Mechanical and Materials Science	.387270	.274730	.338000
Human Ecology			
Family and Child Science	.343896	.279104	.377000
Family Ecology	.389856	.396144	.214000
Food Science	.212652	.084348	.703000
Human Environment	.679758	.138242	.182000
Natural Science			
Biochemistry	.031648	.140352	.828000
Biophysics	.040200	.109800	.850000
Botony & Plant Pathology	.211232	.156768	.632000
Chemistry	.450855	.194145	.355000
Entomology	.131450	.143550	.725000
Geology	.420877	.246123	.333000
Mathematics	.662354	.119646	.218000
Nursing	.761900	.040100	.198000
Physics	.291540	.138460	.570000
Statistics & Probability	.508196	.165804	.326000
Zoology	.397632	.210368	.392000

	Output Shares		
	Undergraduate (M_U)	Graduate (M_G)	Research (M_R)
Social Science			
Anthropology	.406912	.171088	.422000
Criminal Justice	.340868	.330132	.329000
Geography	.393887	.345113	.261000
Political Science	.395395	.157605	.447000
Psychology	.322704	.341296	.336000
Social Work	.436545	.364455	.199000
Sociology	.304486	.332514	.363000
Urban Planning	.569900	.250100	.180000
College of Urban Development			
Urban & Metropolitan Studies	.530400	.013600	.456000

1978-79	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
College of Agriculture and Natural Resources			
Agricultural Economics	.523771	.291057	.185172
Agricultural Engineering	.583529	.285099	.131373
Animal Husbandry	.601567	.185376	.213057
Crop and Soil Science	.668363	.140494	.191143
Dairy Science	.580495	.192928	.226576
Fisheries & Wildlife	.450218	.179009	.370774
Forestry	.784530	.055566	.159904
Horticulture	.587243	.181479	.231278
Packaging	.650428	.253682	.095890
Parks & Recreation	.363922	.407116	.228962
Poultry Sciences	.815373	.061542	.123084
Resource Development	.487001	.280852	.232147
Arts and Letters			
English	.751658	.126095	.122247
English Language Center	.113892	.373280	.512828
German & Russian	.660589	.226619	.112792
History	.713036	.191575	.095388
Linguistics, Oriental and African Languages	.690900	.194146	.114954
Philosophy	.870468	.025251	.104280
Romance & Classical Languages	.684586	.094294	.221119
College of Lyman Briggs	.829773	.080880	.089346

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Business			
Accounting & Financial Administration	.544750	.309811	.145439
Business Law & Office Administration	.428733	.535709	.035557
Economics	.651210	.214915	.133876
Hotel, Restaurant & Institution Management	.478656	.466485	.054859
Management	.601397	.169001	.229602
Marketing	.566959	.231500	.201541
Communication Arts			
Advertising	.166506	.613871	.219624
Audiology & Speech	.675251	.288975	.035774
Communications	.460555	.258826	.280619
Journalism	.639710	.212908	.147382
Telecommunication	.714116	.162037	.123846
Engineering			
Chemical Engineering	.433586	.222677	.343737
Civil Engineering	.709845	.224372	.065783
Computer Science	.775863	.154293	.069844
Electrical Engineering	.724440	.120094	.155466
Mechanical Engineering	.780277	.142016	.077707
Metallurgy, Mechanical and Materials Science	.629576	.249776	.120648

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Human Ecology			
Family and Child Science	.466840	.362568	.170592
Family Ecology	.458739	.399155	.142106
Food Science	.544150	.306830	.149020
Human Environment	.357882	.515158	.126959
College of James Madison	.355722	.591297	.052981
Natural Science			
Astronomy & Astrology	.509630	.461113	.029257
Biochemistry	.507106	.217017	.275877
Biophysics	.603682	.134809	.261509
Botony & Plant Pathology	.676868	.074357	.248774
Chemistry	.409713	.144801	.445486
Entomology	.497781	.267410	.234809
Geology	.636532	.156604	.206863
Mathematics	.591561	.170432	.238007
Nursing	.326740	.642546	.030714
Physics	.701909	.122702	.175389
Statistics & Probability	.711998	.108812	.179191
Zoology	.705879	.049691	.244430
Social Science			
Anthropology	.554073	.326386	.119541
Criminal Justice	.479386	.397324	.123290
Geography	.688983	.109644	.201373
Political Science	.572887	.229971	.197142
Psychology	.708060	.117886	.174054
Social Work	.562452	.407900	.029648

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Social Science (continued)			
Sociology	.731160	.062298	.206541
Urban Planning	.706111	.224819	.069069
College of Urban Development			
Urban & Metropolitan Studies	.631500	.209155	.159344
1977-78			
College of Agriculture and Natural Resources			
Agricultural Economics	.561847	.256742	.181411
Agricultural Engineering	.592177	.244157	.163666
Animal Husbandry	.666102	.107434	.226463
Crop and Soil Science	.740238	.156337	.103425
Dairy Science	.515223	.300998	.183779
Fisheries & Wildlife	.282846	.323873	.393281
Forestry	.701727	.088201	.210071
Horticulture	.658204	.137325	.204471
Packaging	.808039	.171990	.019971
Parks & Recreation	.348349	.442786	.208865
Poultry Sciences	.782744	.101813	.115442
Resource Development	.593832	.186951	.219218
Arts and Letters			
English	.778748	.103320	.117932
German & Russian	.680489	.161519	.157993

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Arts and Letters (continued)			
History	.703529	.186664	.109806
Linguistics, Oriental and African Languages	.736352	.170692	.092956
Philosophy	.856972	.055835	.087192
Romance & Classical Languages	.705812	.077105	.217082
Business			
Accounting & Financial Administration	.603451	.190784	.205765
Business Law & Office Administration	.494642	.496529	.008828
Economics	.727584	.141058	.131358
Hotel, Restaurant & Institution Management	.534809	.403573	.061618
Management	.640697	.134661	.224643
Marketing	.673995	.104087	.221918
Communication Arts			
Advertising	.314410	.435868	.249722
Audiology & Speech	.416179	.456632	.127189
Communications	.405859	.217715	.376426
Journalism	.578822	.217829	.203349
Telecommunication	.752639	.063634	.183726
Engineering			
Chemical Engineering	.607072	.177771	.215157
Civil Engineering	.647834	.286061	.066105

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Engineering (continued)			
Computer Science	.792894	.136729	.070377
Electrical Engineering	.765695	.069974	.164331
Mechanical Engineering	.774323	.151549	.074128
Metallurgy, Mechanical and Materials Science	.748808	.172539	.078652
Human Ecology			
Family and Child Science	.542365	.271435	.186201
Family Ecology	.412347	.472158	.115494
Food Science	.386795	.208174	.405031
Human Environment	.409115	.496336	.094549
Natural Science			
Biochemistry	.525532	.234724	.239744
Biophysics	.590585	.246405	.163010
Botony & Plant Pathology	.715730	.072317	.211952
Chemistry	.407248	.129394	.463357
Entomology	.409077	.330454	.260469
Geology	.624778	.185733	.189489
Mathematics	.645197	.130693	.224110
Nursing	.236698	.738358	.024944
Physics	.682234	.142300	.175465
Statistics & Probability	.722041	.106694	.171265
Zoology	.682379	.043162	.274458

	Input Shares		
	Tenured Faculty (S_T)	Non-Tenured Faculty (S_N)	Graduate Assistants (S_A)
Social Science			
Anthropology	.561933	.318876	.119192
Criminal Justice	.516037	.344566	.139398
Geography	.616819	.162452	.220730
Political Science	.545903	.232300	.221797
Psychology	.528837	.334367	.136796
Social Work	.676379	.290638	.032982
Sociology	.755181	.072137	.172681
Urban Planning	.585648	.306121	.108230
College of Urban Development			
Urban & Metropolitan Studies	.559842	.167143	.273015

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