DOCUMENT RESUME

ED 119 016 CE 006 615

AUTHOR	Massell, Adele P.; Hosek, James R.
TITLE	Estimating the Effects of Teaching on the Costs of Inpatient Care: The Case of Radiology Treatments.
INSTITUTION	Rand Corp., Santa Monica, Calif.
SPONS AGENCY	Department of Health, Education, and Welfare, Washington, D.C. Office of the Assistant Secretary for Planning and Evaluation.; Health Resources Administration (DHEW/PHS), Bethesda, Md.
REPORT NO	R-1751-HEW
PUB DATE	Aug 75
NOTE	39p.
AVAILABLE FROM	Rand Corporation, Santa Monica, California ($3.00)
EDRS PRICE	MF-$0.83 HC-$2.06 Plus Postage
DESCRIPTORS	*Cost Effectiveness; Costs; Data Analysis; Health Services; Hospitals; Medical Assistants; Medical Education; Medical Evaluation; Medical Schools; *Medical Services; *Medical Students; Medical Technologists; Medical Treatment; Models; Physicians; Primary Health Care; *Productivity; *Radiology; Student Employment
IDENTIFIERS	*Teaching Hospitals; Veterans Administration

ABSTRACT

The report investigates production and the cost effects of teaching within hospital departments. Models of primary production show that the cost effects of teaching are determined by the salaries paid to students (including residents, interns, medical students, and technical trainees) and physicians, by the levels of student inputs used in production, and by the productivity of student and nonstudent inputs. The models of departmental production developed permit costs to be related to the level of student inputs rather than to the more abstract variable, teaching output. Empirical analyses of radiology costs in 90 general medical and surgical hospitals in the Veterans Administration system were conducted. The empirical results suggest that, with the exception of one variable whose interpretation is suspect, teaching reduces costs for most individual radiology procedures. Although the VA system differs from non-VA hospitals in many respects, the apparent cost reductions for many radiology outputs suggest that students can be substituted for nonstudent inputs in radiology. If costs of primary products can be reduced through teaching, as the radiology results suggest, it would be possible for teaching hospitals to provide a given medical program for patients at lower costs than in nonteaching hospitals. (Author/JR)

ESTIMATING THE EFFECTS OF TEACHING ON THE COSTS OF INPATIENT CARE: THE CASE OF RADIOLOGY TREATMENTS

PREPARED FOR THE HEALTH RESOURCES ADMINISTRATION AND THE OFFICE OF THE ASSISTANT SECRETARY FOR PLANNING AND EVALUATION OF THE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

ADELE P. MASSELL
JAMES R. HOSEK

R-1751-HEW
AUGUST 1975

Rand
SANTA MONICA, CA 90406

ESTIMATING THE EFFECTS OF TEACHING ON THE COSTS OF INPATIENT CARE: THE CASE OF RADIOLOGY TREATMENTS

PREPARED FOR THE HEALTH RESOURCES ADMINISTRATION AND THE OFFICE OF THE ASSISTANT SECRETARY FOR PLANNING AND EVALUATION OF THE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

ADELE P. MASSELL
JAMES R. HOSEK

R-1751-HEW
AUGUST 1975

Rand
SANTA MONICA, CA. 90406

$3.00

CE 006 615

PREFACE

The research in this report is the joint product of two Rand health research projects: (1) a project concerned with the effects of federal programs on academic medical centers, supported by the Bureau of Health Resources Development of the Health Resources Administration (HRA) and by the Office of the Assistant Secretary for Planning and Evaluation, Department of Health, Education, and Welfare (HEW) (Contract No. NO1-MB-24196, formerly NIH 72-4196); and (2) a project concerned with the development of methodological frameworks for evaluating hospital costliness and productivity, supported by the Bureau of Health Services Research and Evaluation, HRA, HEW (Grant No. 5 RO1 HS01152-02).

The work reported here concerns the interaction between the teaching and patient care activities of hospitals—specifically, the role of teaching in determining the costs of inpatient care. In the analysis, the authors postulate that teaching may affect both the cost of the services produced and the pattern of their utilization in patient care. The report focuses on the costs of producing the outputs of a single hospital department, Radiology; proposed future research would examine the outputs of other departments and factors affecting the use of departmental products and services in caring for individual patients. The report develops theoretical models of the effects of teaching on production costs, using the models as a basis for empirically examining Radiology costs in general medical and surgical hospitals within the Veterans Administration system.

SUMMARY

The effects of hospital-based teaching on the cost of providing inpatient care is an issue of current policy interest. Policy areas in which teaching effects are an important issue include health manpower training programs and the medical cost reimbursement policies of federal and private insurers. Decisions are being made in these areas although there is little empirical evidence on the existence and magnitude of teaching effects and no evidence on how teaching affects costs.

To analyze teaching effects, it is necessary to analyze the structure of cost determination in hospitals. The present study uses a conceptual view of hospital operations that permits a partial separation of aspects of cost determination. According to this view, hospitals consist of departments that produce primary components of care (such as X-rays, surgeries, and prescriptions); they, in turn, are combined to form the diagnostic and treatment program administered to a patient. Based on this bilevel production framework, cost determination can be analyzed at each production level.

This report investigates production and the cost effects of teaching within hospital departments. Models of primary production show that the cost effects of teaching are determined by the salaries or fees paid to students (including Residents, Interns, Medical Students, and Technical Trainees) and physicians, by the levels of student inputs used in production, and by the productivity of student and nonstudent inputs. If students are substitutes for other, more costly inputs (e.g., physicians), production costs may be less in teaching than in nonteaching departments producing a given level of output.

The models of departmental production developed here provide a basis for empirical analysis. A particular advantage of the models is that they permit costs to be related to the existence or level of student inputs rather than to the more abstract variable, teaching output. To illustrate the application of the models, we conduct empirical analysis of Radiology costs in 90 General Medical and Surgical Hospitals in the Veterans Administration system.

The empirical results suggest that teaching (specifically, training Residents and Technical Trainees) reduces costs for most individual Radiology procedures. There is one output variable, however (examinations performed outside the department), whose interpretation is suspect and for which the estimated cost effect is very large and positive. Estimates of the overall departmental cost effect of teaching are dependent on the interpretation of this variable and its coefficient.

Although the VA system differs from non-VA hospitals in many respects, the apparent cost reductions for many Radiology outputs in the VA suggest that, in general, students can be substituted for nonstudent inputs in Radiology and that, to the extent the VA uses technology similar to that of non-VA Radiology departments, cost savings may be available to non-VA departments.

If costs of primary products can be reduced through teaching, as our Radiology results suggest, it would be possible for teaching hospitals to provide a given medical program for patients at lower costs than in nonteaching hospitals. However, teaching hospitals may tend to provide different treatment patterns from those of

nonteaching hospitals, because of differences in either case mix, medical techniques, or quality of care. Analyses of these sources of cost differences are proposed for future research.

ACKNOWLEDGMENTS

The authors would like to thank the staff members of the Veterans Administration Central Office, especially Daniel Rosen and Carl Evans, for their aid in obtaining data on cost, output, and teaching in VA hospitals. Robert P. Inman and Anthony H. Pascal reviewed the paper and offered many useful suggestions for improvement, as did Craig B. Foch. Kent Brown and Esther Uyehara provided programming and computation assistance, and Martha Cooper typed draft after draft of the manuscript. Finally, the authors are grateful to Richard V. L. Cooper and Albert P. Williams, Jr., for their general guidance and support throughout the project.

CONTENTS

I. INTRODUCTION

It is widely assumed that the costs of providing inpatient care are higher in teaching than in nonteaching hospitals.[1] There is considerable debate, however, about the causes of higher costs. Critics of teaching hospitals allege that residents and interns order excessive (and unnecessarily costly) tests and medical supplies, that physicians are diverted from patient care to teaching activities, that teaching hospitals overemphasize technologically sophisticated equipment and techniques, and that teaching hospitals are generally inefficient. In rebuttal, supporters argue that teaching hospitals treat more complex, diverse, and, therefore, more costly cases and that they provide higher quality care; some supporters, while acknowledging that hospital-based costs may be higher, suggest that this reflects the substitution of hospital services (including the services of house staff and students) for costly professional services and that the total costs of care (hospital costs plus professional fees) may not be higher in teaching hospitals.

Despite the fairly large body of previous research on hospital production and costs, there is little empirical evidence on the specific issue of teaching effects, and what there is is far from conclusive. In examining the statistical relationship between hospital-based costs and measures of hospital activity and output (i.e., case mix; patient characteristics, case load, hospital capacity, urban location, length of stay, and the existence of more or less advanced teaching programs), Lave, Lave, and Silverman[2] find some tendency for higher costs attributable to advanced teaching but a tendency for lower costs attributable to less advanced teaching; however, these results lack strong statistical significance. In analyzing the relationship between hospital-based costs and variables describing hospital scale, the mix of patient services, and several aspects of teaching activity, Carr and Feldstein[3] observe higher costs per resident or intern, but negative or mixed effects for nursing school affiliation, medical school affiliation, and the numbers of nursing students; the statistical properties of these results vary from one empirical specification to another. Salkever,[4] adjusting for hospital size and case mix, finds that average hospital-wide costs increase significantly as the ratio of medical students to cases increases but are not statistically related to the ratio of nursing students to cases. In an unusual study whose cost data include professional fees, Slighton and Bell[5] find that there is no difference in total costs per patient once diagnosis, surgery, and length of stay are taken into account; unfortunately, this evidence derives from a small and geographically limited sample of hospitals.

[1] Sources of this view are difficult to document. However, in our discussions with health care professionals—including administrators of teaching hospitals—we found the view to be nearly universal.

[2] Judith R. Lave, Lester B. Lave, and Lester P. Silverman, "Hospital Cost Estimation Controlling for Case-Mix," *Applied Economics*, Vol. 4, No. 3, September 1972, pp. 165-180.

[3] John W. Carr and Paul J. Feldstein, "The Relationship of Cost to Hospital Size," *Inquiry*, Vol. 4, March 1967, pp. 45-65.

[4] David S. Salkever, *Studies in the Economics of Hospital Costs*, Ph.D. dissertation, Harvard University, Cambridge, Massachusetts, 1970, pp. 58-87, 106-117.

[5] Robert L. Slighton and Robert M. Bell, "The Total Costs of Medical Care in Teaching and Nonteaching Settings" (draft), The Rand Corporation, June 24, 1974.

Conclusive evidence on whether costs are higher in teaching hospitals is necessary but not sufficient to resolve contemporary policy issues; reasons for the cost differences must also be identified. One current policy issue of primary interest to federal agencies responsible for health manpower training programs is whether growth in teaching programs will contribute to inflationary pressures in the market for inpatient care. To resolve this issue, policymakers require information not only on whether costs are higher in teaching hospitals but, for example, on whether the cost differential depends on the size of hospital teaching programs or on the kinds of hospitals (e.g., large or small, profit or nonprofit) in which the programs are located. A second policy issue is whether public programs for providing health care to the disadvantaged (e.g., Medicare, Medicaid) are paying more than their fair share of the costs incurred in teaching hospitals—that is, whether the public agencies are providing an unintended subsidy of teaching programs. The answer to this question again involves not only a comparison of costs in teaching and nonteaching hospitals but information on whether the cost differences are justified by differences in the kinds or quality of care being provided.

This report is an outgrowth of research concerned with identifying the existence, magnitude, and causes of cost differences among hospitals. This study analyzes the structure of production in teaching and nonteaching hospitals and determines how costs of patient care are generated within these structures. To carry out the analysis, we use a model of hospital behavior in which two levels of productive activity are involved in providing patient care. At the primary level, hospitals produce specific products and services used in treating patients. Examples are medication orders prepared in the hospital pharmacy, specific laboratory tests, surgeries, X-rays, and meals. The second level of production involves the formulation of a treatment program for each patient, consisting of the set of primary components administered to the patient for diagnosis and treatment.

Given this view of production, there are two distinguishable kinds of potential cost effects of teaching. The first is the effect that teaching may have on the costs of primary production. For example, because students[6] are less skilled, they may reduce the efficiency of production or may make errors that require duplication of tasks. Alternatively, students may take the place of more costly hospital employees in production. The second kind of potential teaching effect is on the formulation of treatment programs. For example, students may seek to reduce the likelihood of diagnostic error by ordering more kinds of laboratory tests; alternatively, teaching hospitals, by virtue of their highly qualified staffs or the facilities at their disposal, may tend to receive patients requiring more extensive care or to provide more technologically sophisticated or higher quality care.

Although we currently plan to investigate both kinds of teaching effects, the analysis here focuses on the effects at the primary level of production. In several respects, primary production is especially amenable to economic analysis. In comparison with the output of health care, which is influenced by patient characteristics and by the entire treatment program provided and is therefore difficult to measure, the output of a primary component of treatment, such as a skull X-ray, is fairly easy to quantify. Moreover, primary production generally occurs within readily identified and semi-autonomous productive units within the hospital

[6] We use the term "students" to refer to Residents, Interns, and Trainees as well as Medical Students. The term "physician" is reserved for fully qualified, nonstudent personnel.

(i.e., departments), and many of these units (e.g., Radiology, Pharmacy, Pathology) seem to operate much like firms or businesses, for which there are many existing paradigms in economic theory.

Finally, there is likely to be considerable similarity among hospitals in the production processes for primary outputs; for example, consider the production of a diagnostic X-ray: The patient must be prepared, certain supplies such as film must be used, a specific type of capital equipment must be used, and skilled labor is required. Thus, the nature of the procedure itself and factors that influence its production costs are likely to be quite uniform among hospitals. This is in contrast to analyses of costs per bed-day or per episode, where differences in institutional structure or patient characteristics can considerably affect the cost comparisons.

To investigate primary production, we develop models of the way in which the use of student labor in production can affect costs. From our models, we conclude that the cost effects of teaching will depend on the salaries paid to students, on the productivity of student labor relative to fully skilled labor, and on the levels at which student labor is used. Under certain conditions, the models suggest that the use of students can lead to a *reduction* in the costs of producing primary services in hospitals. Whether potential reductions are translated into lower costs of patient care, however, depends on whether hospitals use students in the most cost-effective manner and on whether differences in patterns of treatment offset any savings at the primary level of production.

We have empirically analyzed department costs using data from Veterans Administration hospitals. The departments under investigation provide Radiology services; these departments were chosen for this initial analysis because the VA output measures are especially detailed, the outputs themselves are likely to be particularly homogeneous among hospitals, and decisions concerning output levels are largely exogenous to the department. As a consequence, the analysis focuses on issues involved in specifying the production process, thereby laying a firm empirical foundation for extending the models in future research. The evidence obtained in the empirical analysis suggests that teaching permits lower costs of producing many Radiology outputs for our sample of VA hospitals.

In Section II we develop the theoretical analysis of primary production. Section III reports results from applying the theory to production in VA Radiology departments. Implications of the theoretical and empirical results are discussed in Section IV.

II. THEORETICAL ANALYSIS OF THE EFFECTS OF TEACHING ON PRIMARY PRODUCTION COSTS

The conceptual framework underlying this study is based on the view that hospital production consists of two levels. Primary production, which is performed in or managed by departments within a hospital, includes the production of individual diagnostic and treatment services and products (e.g., blood-pressure tests, prescribed medication). At the second level of production, primary outputs are combined in administering a diagnostic and treatment program for a patient.

In this section we apply economic theory to investigate the effects of departmental teaching on the costs of *primary* production. We bypass the question of how primary output levels are determined. The department may respond to orders placed by other departments or by private physicians (as would generally be the case for Radiology, Pharmacy, Laboratory), or the department may exercise some discretion in choosing output levels (as would be true in Surgery and Medicine). Whatever the decision process determining output, our analysis addresses the question of how teaching can affect the costs of producing the chosen level of output.

Although we use the conceptual framework developed here to analyze costs in Veterans Administration Radiology departments, the conceptual framework itself is not specific to a particular department or a particular institution. Indeed, the purpose of developing the models presented here is to identify the factors that determine whether teaching will raise, lower, or leave unchanged the costs of primary production so that cost effects under alternative management and production conditions can be derived.

There are three restrictions on the applicability of the models. First, we confine attention to production of services at a constant level of quality. For example, in describing the substitution of students for physicians in production, we assume that substitution is constrained by the condition that the quality of output be unaffected. Thus, cost effects that operate through changes in quality would be superimposed on the kinds of cost effects examined here.

Second, in examining an individual primary product, we assume that there are no cost effects due to differences in the kind of patient to whom the product is administered. If, for example, a particular surgical procedure is performed differently on a child than on an adult, then the two kinds of surgery should be treated as separate services; and the models should be used to consider potential teaching cost effects for each of the services separately.

Third, we assume that the production processes for individual primary outputs are mutually independent. Although primary products are generally produced in hospital departments with highly specialized production responsibilities, it is nevertheless true that not one but several kinds of products are produced by a single department. To some extent the production processes may overlap, so that, for example, there may be a single developing lab used in producing a variety of radiology services. Although the overlapping of technical processes may imply that the cost of producing skull X-rays is affected by the production levels of other services and thus may differ among departments producing differing mixes of services, such cost effects are ignored. The nature of our conclusions about teaching effects would be affected by treating production interdependencies only if they have substantial effects on costs and if teaching activities are closely related to the exploitation of production interdependencies.

For theoretical analysis, the foregoing restrictions help us to distinguish the technological implications of teaching from cost differences that may be associated with—but not necessarily caused by—teaching. We recognize that such distinctions are difficult to incorporate in empirical comparisons of costs, and we have taken this into account in selecting Radiology departments for the present empirical analysis. We shall address the issues of quality variation, patient differentiation, and production interdependencies with respect to our empirical analysis in Section III.

To set the stage for considering the cost implications of teaching, we begin with a description of the production model underlying the analysis.

PRIMARY PRODUCTION: A CONCEPTUALIZATION

Consider the production of a single treatment component, say a diagnostic skull X-ray. There is a technological relationship, described by a production function, between levels of various productive inputs and the level of output. Let Q be the number of skull X-rays produced, and let X_1 through X_n be the quantities of each of n inputs (e.g., physicians' hours, technicians' hours, capital equipment, utilities); a general form of the production function is:

$$Q = f(X_1, \ldots, X_n). \tag{1}$$

To define a specific production technology, a particular functional form and parameter values[7] replace the general function, f. In the economic analysis of production, very often too little is known about technology to define a production function in detail. Nevertheless, certain properties of the functional form and parameter values can often be set on an *a priori* basis, and the properties alone may provide sufficient information to draw broad conclusions about production behavior. In this model, the ability to draw conclusions about teaching effects relies on the assumption that the same production technology for producing Q is used in teaching and nonteaching departments. We make this assumption despite two potential sources of differences in technology between teaching and nonteaching departments: (1) Teaching departments use students in producing Q while nonteaching departments do not; and (2) in teaching departments, the production processes for teaching and patient care are interdependent. These two factors warrant further consideration.

Although both teaching and nonteaching departments use many of the same inputs, such as capital equipment, supplies, utilities, and skilled labor, teaching departments also use student labor, which is not used in nonteaching departments.

[7] An example of a specific production technology is $Q = X_1^{.2}X_2^{.5}$, where X_1 = number of manhours of physician time and X_2 = number of machine hours for a particular piece of capital equipment. In the example, the functional form is

$$f(X_1, X_2) = X_1^{\alpha_1}X_2^{\alpha_2},$$

where α_1 and α_2 are fixed parameters. The example sets the parameter values as $\alpha_1 = .2$ and $\alpha_2 = .5$.

The most general approach to modeling this condition is to postulate that the two types of departments use different production technologies (and, therefore, have different production functions). A useful and plausible alternative, however, is to postulate that Q is produced according to a single production function using labor, capital, and other inputs but that the composition of the labor input differs between teaching and nonteaching departments. Thus, we suppose there are combinations of student and physician labor that yield services equivalent to those provided by physicians alone in a nonteaching department. This is incorporated in our models by restricting attention to specifications of Equation (1) that permit nonzero output of Q even when student inputs are zero. This aspect of the model is illustrated below geometrically.

The second factor to be considered is the relationship between primary production and the production of teaching services. Teaching and patient care are frequently described as joint products; the term is a technical one, implying not only that two or more products are produced in the same firm but that at least some of the inputs used in production contribute simultaneously to producing more than one output. Since students learn from observing and participating in patient care, the inputs used in providing patient services also contribute to teaching output. Thus, teaching and primary outputs are joint products, and the production functions for the two kinds of products are not independent.

Although there are many ways to specify joint production functions, the specification used here is particularly amenable to cost analysis and is consistent with the apparent properties of teaching and patient care production.[8] Specifically, we postulate that a production function for teaching, T, can be written:[9]

$$T = g(Q, X_1 \ldots, X_n), \tag{2}$$

or, substituting for Q from Eq. (1);

$$T = h(X_1, \ldots, X_n). \tag{3}$$

Equation (2) reflects the assumption that both the production of primary output, Q, and the use of inputs in producing Q affect teaching output. For example, we might postulate that more teaching output is achieved when students observe more patient care and, for a given level of patient care, more teaching output is achieved by having students participate more fully in providing care.

Equations (1) and (3) represent joint production because we assume that each input to one of the production processes is fully and simultaneously used as an input to the other production process;[10] in the act of producing a skull X-ray, for example,

[8] However, the specification takes a form somewhat different from the familiar one in models of joint production. Letting T = teaching output, the familiar joint-production specification would be written: $H(T, Q) = G(X_1, X_2, \ldots, X_n)$. It is generally assumed that this function identifies a production frontier in Q and T (given $X_1, \ldots, X_n$) that is concave to the origin. Such a specification is not appropriate to the current case since we assume that T is nonzero if and only if Q is nonzero. Thus, contrary to the conventional model, we seek a specification in which $T > 0$ implies $Q > 0$. The specification we use possesses this property. Incidentally, our specification implies that there is one and only one combination of T and Q produced from a given set of inputs. Hence, the production frontier consists of a single point for each input set.

[9] Note the conceptual distinction between T, which is an index reflecting the quality and quantity of knowledge made available to students, and the input of student labor, which is the number of manhours of student time used in producing both T and Q.

[10] Note that although we use separate equations for T and Q production, the model nevertheless describes joint production because the inputs to the two processes are not separate. To be mathematically

a physician in a teaching department is assumed to be providing a learning experience for students. By implication, once a department selects the set of inputs to be used in production, both Q and T are determined.

The specification does not necessarily imply that teaching and primary outputs are produced in fixed proportions. If alternative input combinations can be used to produce a given quantity of Q, then a department may be able to vary T while Q is held constant, simply by changing the choice of inputs. To illustrate this property, the curve in Fig. 1 shows various combinations of physician (P) and student (S) labor inputs that can be used to produce a given level of Q output (holding all other inputs fixed). The points describing such input combinations form a curve called a production isoquant. At point A on the isoquant, no students are used in production; consequently, teaching output is zero, and A is the production point of a nonteaching department. Production points on the isoquant to the right of A are attained by using students as well as physicians in production. At point B, for example, the output of Q is the same as at point A, but student inputs are nonzero and teaching output is presumably nonzero. Similarly, other points on the curve represent levels of teaching output different from those at both A and B even though all such points result in the same level of Q output.[11]

COST EFFECTS OF TEACHING

As indicated, movement along the isoquant in Fig. 1 implies changes in teaching output, holding Q output constant. It is difficult to specify *a priori* how teaching varies along the curve. Suppose teaching output tends to increase with the number of students but, at the same time, also tends to increase with the physician-student ratio. If these two measures vary inversely along the isoquant (as in Fig. 1), then a given movement along the curve may, on balance, result in either increased or decreased teaching output.

We do not need to measure teaching output in order to evaluate the cost effects of movement along the isoquant, because we are able to make a direct observation of the correspondence between costs and levels of student inputs. Initially, we assume that all departments face the same input prices[12] and consider the case in which all departments producing a given level of primary output, Q_0, use the same quantities of all inputs except physicians and students. Under these conditions, we need examine only physician and student costs to make cost comparisons between teaching and nonteaching departments.

In addition to the isoquant, Q_0, Fig. 1 illustrates two isocost lines. Points on an isocost line show the alternative combinations of physician and student inputs that

precise, the specification might be written: $H(X_1, \ldots, X_n) = F(Q) = G(T)$. As a consequence of this specification, costs for producing the two outputs jointly are not the sum of the costs of producing them separately. This behavior of costs has been used by Robert Hall as a characteristic defining joint production. See "The Specification of Technology with Several Kinds of Output," *J. Polit. Econ.*, Vol. 81, No. 4, July/August 1973, p. 884.

[11] The same argument can be used to describe how Q can be varied while T output is held constant. The analysis involves considering alternative Q isoquants that intersect points on a single T isoquant.

[12] It is assumed that student wages are given and not a function of the level of teaching or medical output at the hospital. Because of the centralized administration of salaries in VA hospitals, wages vary little for the sample we will use in our empirical analysis; hence, we do not consider the implications of relaxing this assumption.

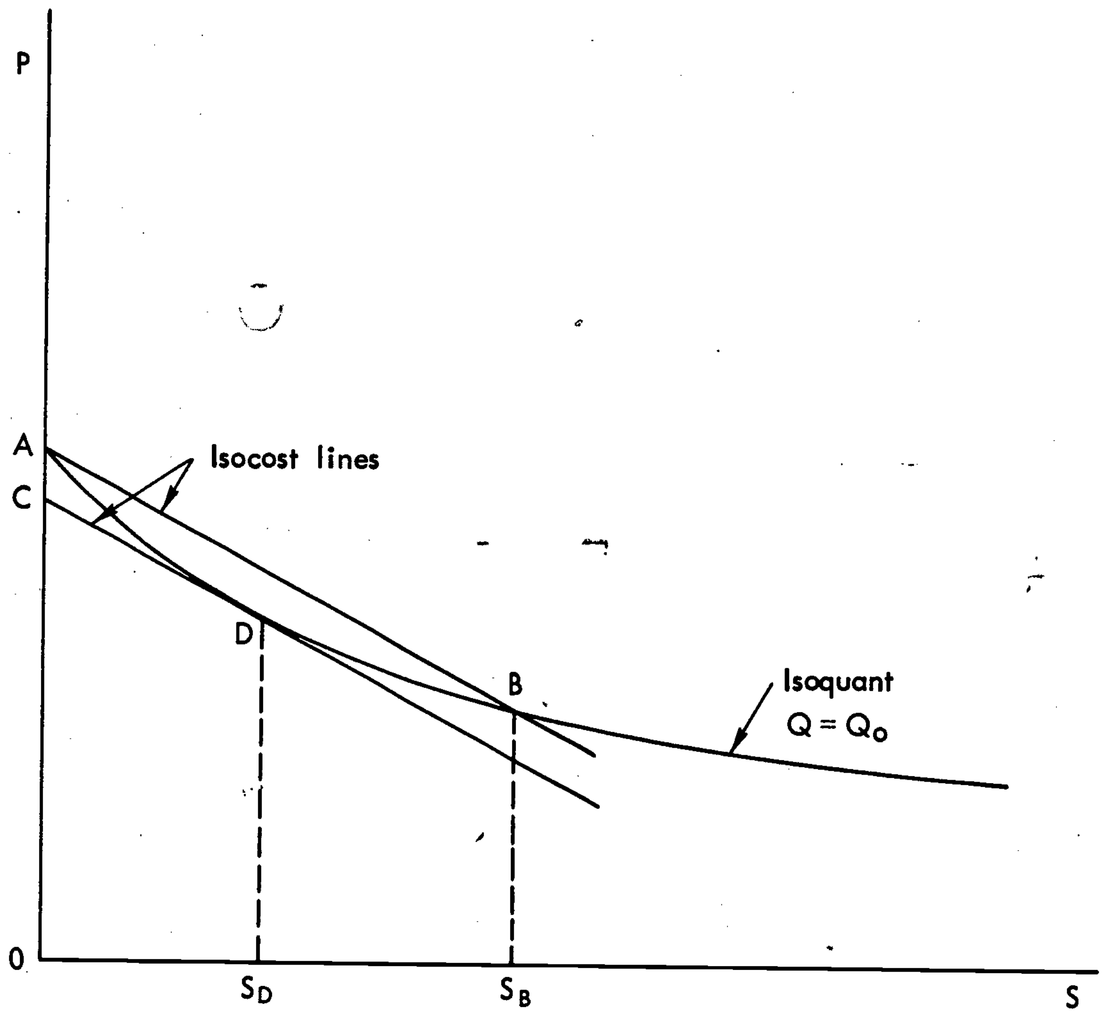

Fig. 1—Cost comparisons

can be purchased at the same total costs; the higher is an isocost line in the figure, the larger is the budget to which it corresponds. Although Fig. 1 shows only two isocost lines, there is an isocost line corresponding to each point on the isoquant for Q.

The figure shows that a teaching department operating at point B on the isoquant has the same costs as a nonteaching department operating on point A, for both departments are operating on the same isocost line. If Fig. 1 accurately reflects production in teaching and nonteaching departments producing the Q_0 level of output, then production costs would be equal for the two departments, provided the teaching department uses S_B student inputs.

If a teaching department uses more than S_B student inputs to produce Q_0, however, the department will be operating to the right of point B and above the upper isocost line in Fig. 1. Thus, the teaching department would be more costly than the nonteaching department operating at point A. However, if the teaching department uses less than S_B student inputs, the department would be operating at points *below* the upper isoquant—and the teaching department would be *less* costly than the nonteaching department. In particular, if the teaching department operates at point D, using student inputs S_D, the department would be on the lowest feasible isocost line (the lower line shown in the figure); it would be minimizing Q_0 production costs and would be more cost effective in Q_0 production than the nonteaching department.

It is apparent that teaching departments may have *lower* or *higher* costs than nonteaching departments. As student inputs increase, costs fall, reach a minimum at $S = S_D$, then rise, become equal to nonteaching costs at $S = S_B$, and then continue to rise as S increases beyond S_B. The extent to which teaching increases or reduces costs is clearly dependent on the level of utilization of student inputs.

Other factors affect the extent of cost differences between teaching and nonteaching departments. Student and physician salaries are an important determining factor. By definition, the slope of the isocost lines is equal to the ratio of physician salaries (or fees) to student salaries.[13] The higher are physician salaries relative to student salaries, the flatter are the isocost lines; more students can be used without generating increased total costs. For example, if the isocost line through point A were flatter, it would intersect the isoquant to the right of point B, and a teaching department operating at B would become less costly (rather than equally costly) than the nonteaching department.

Another factor affecting cost determination is the productivity of students relative to physicians. In Fig. 1, we assume that students can be substituted for physicians in producing Q_0. It might be true, however, that substitutability is quite limited or nonexistent. We consider three alternative isoquants for Q_0: Figure 2(a) shows limited substitutability, Fig. 2(b) shows no substitution, and Fig. 2(c) shows the case in which *more* physicians are required to produce Q_0 when students are involved. For each of the three cases, all points on the isoquant to the right of the P axis lie above the isocost lines for nonteaching departments. Therefore, if any of these isoquants is relevant for a particular primary output, teaching offers no opportunity for cost reductions. Other things equal, the cost effects of teaching a given number of students, such as S^*, will be greatest in the case illustrated by Fig. 2(c) and least in the case illustrated by Fig. 2(a).

Yet another factor affects teaching costs but is not taken into account in the preceding analysis: Teaching and nonteaching departments may differ in the use of nonlabor inputs[14] in production. More generally, departments may differ not only in the composition of the labor input but in the combination of labor and nonlabor inputs. Thus, even if it is possible to use the same labor-nonlabor combination at lower cost in a teaching department (as shown in Fig. 1) teaching may lead a department (either by choice or because of teaching constraints) to use a more costly combination of inputs. Even if labor is more costly in a teaching department (as in Fig. 2), part of the cost disadvantage may be offset by a tendency to substitute capital or other inputs for labor.

[13] If physician salaries are W_P and student salaries are W_S, then a one-unit reduction in physician inputs releases W_P in the budget, which will purchase W_P/W_S number of student inputs. The slope of the isocost line is the ratio of changes in physician to student inputs $= 1/(W_p/W_S) = W_S/W_P$. (Algebraically, the sign of this slope is negative.)

[14] Strictly speaking, the term "nonlabor inputs" is a misnomer. What is intended is the set of all inputs excluding physicians and students.

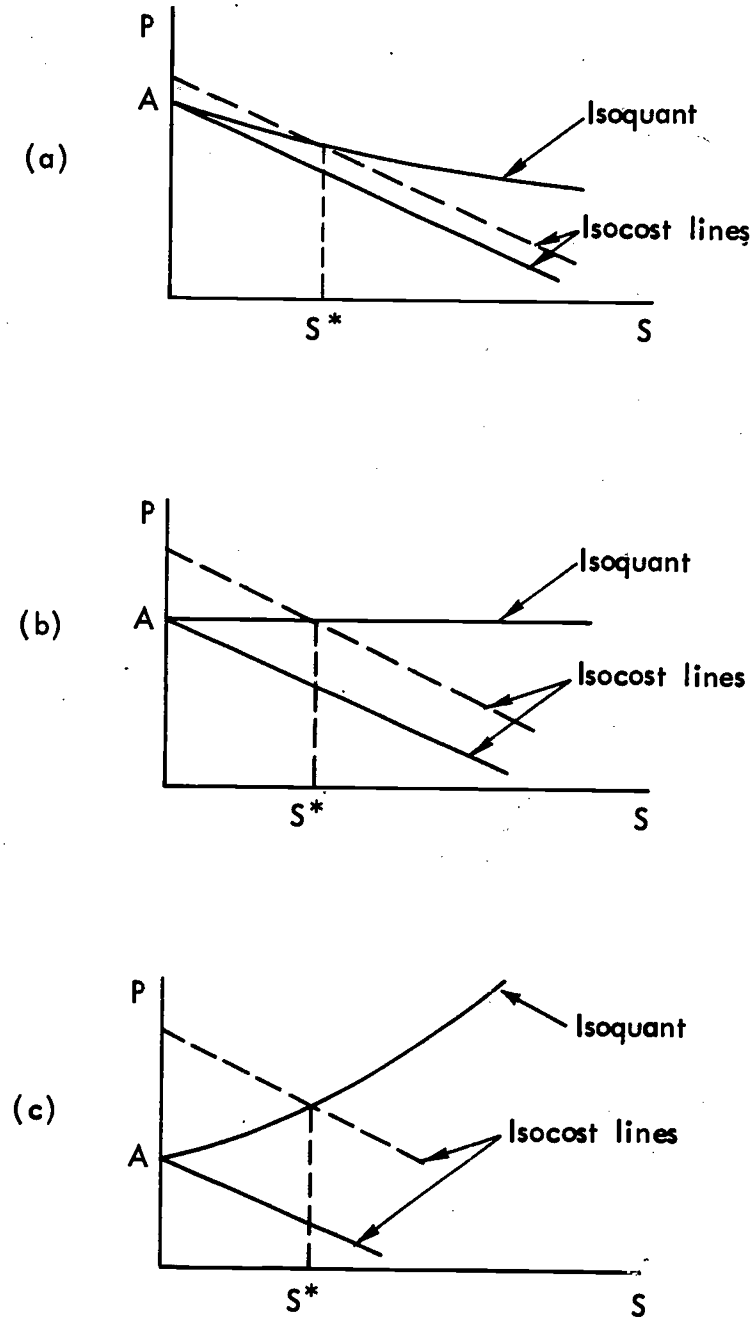

Fig. 2—Cost effects with alternative isoquants

In summary, the cost effects of teaching in a department depend upon: (1) departmental production technology (i.e., the shape of the isoquant at each output level); (2) prices of inputs (e.g., physician and student salaries); and (3) department decisions concerning input utilization. The first two of these factors are largely outside departmental control, and the last is discretionary. Thus, even if technology and input prices permit cost reductions from teaching, departments may not effectively choose to reduce costs. We now turn to a consideration of models of department decisionmaking that suggest how and why cost reductions may or may not be observed even when they are feasible.

OPTIMIZATION AND COST OUTCOMES

A number of hospital objectives have been postulated in previous economic studies,[15] and no single hypothesis is widely accepted. Since different hypotheses yield different conclusions about the cost implications of hospital behavior, we consider here the theoretical cost implications of some alternative hypotheses. Throughout the analysis we assume that the production levels for primary outputs are predetermined.

Minimizing the Cost of Primary Care Outputs

Suppose departments attempt to minimize the costs of production without constraints on inputs or teaching output. By definition of the case, a department would teach only if teaching reduces production costs; if we consider a set of departments with the same cost structures, then all the departments producing a given level of a given primary output would either use students or choose not to use students in production. If teaching is conducted, the level of student inputs for a given output level would be the minimum-cost level of student inputs, which, in turn, would be equal across departments.

This does not imply that departments differing in output level would all use the same student inputs. It is possible, for example, that a particular level of teaching becomes cost effective only at high output levels.[16] Thus, the cost-minimization hypothesis is not inconsistent with the casual observation that larger departments tend to have larger teaching programs.

Cost Minimization with Student Input Constraints

Departments may face constraints in choosing student input levels. Either hospital commitments to a medical school program (or the lack of such commitments) or the requirements for providing a well-rounded teaching program may constrain departmental decisionmaking. The department may have to use more or fewer students than would be cost effective, or the department may be able to choose

[15] For a discussion of the hypotheses, see Karen Davis, "Economic Theories of Behavior in Nonprofit Hospitals," *Econ. and Bus. Bull.*, 24:2, Winter 1972, pp. 1-13.

[16] This might occur, for example, if the marginal rate of substitution of students for physicians (given the level of student inputs) is an increasing function of the level of output. Then, as output increases, the production isoquant acquires an increasingly negative slope at each level of student inputs, and portions of the isoquants for high output levels might then lie below the relevant isocost line.

overall levels of student inputs but may be constrained in assigning students to the production of each kind of primary output.

First, suppose that only the distribution of student inputs among output production processes is constrained. Then, if the department attempts to minimize costs, it will conduct teaching only if the balance of the cost effects over the full range of output processes is favorable. In this case, the level of student inputs would be determined not only by the level of output for individual primary products but by the composition of the set of primary outputs produced by a department. It may be that some primary outputs would be more costly in teaching than in nonteaching departments while other outputs were less costly. However, it would be observed that all departments with a given mix and level of primary outputs would use the same student inputs, and—by the hypothesis under consideration—would teach only if teaching reduces overall departmental costs.

If the total input of students is also constrained, it would not necessarily be possible for teaching departments to be cost effective. However, if the predetermined level of student inputs implies higher labor costs, the department might partially offset the cost disadvantage by substituting nonlabor inputs for labor inputs. We might expect to observe, for example, less capital utilization (at a given level of primary output) in constrained teaching departments than in similar nonteaching departments.

Teaching Output Preferences

If departments have preferences for teaching output, an unconstrained department might be observed to have higher costs due to teaching. The department might choose student input levels that are not cost effective, and because nonlabor inputs may contribute to teaching output, the department might not even attempt to offset the cost disadvantage by substituting nonlabor for labor inputs.

Other Decision Models

From the foregoing, it is readily apparent that a number of factors enter into determining the level and mix of student inputs. Models can be developed, for example, in which teaching output affects the availability of students or their quality. For this initial analysis of VA data, we assume that the proportion of departmental student inputs used in each production process is equal across departments and that overall student input levels are predetermined. To distinguish empirically among the models of input determination would require more detailed data and a larger sample than are currently available. Nevertheless, the foregoing discussion of decision models is useful in illustrating that our production models and empirical analysis do not presuppose whether teaching raises or lowers departmental costs.

PREDICTING COST EFFECTS

This section has shown that in order to predict *a priori* the cost effects of teaching it is necessary to know: (1) the relative salaries of students and physicians; (2) the parameters of the production functions for each primary output; and (3) the objectives and constraints of departments. The last two of these are difficult to specify on an *a priori* basis; the last probably differs among departments operating in different institutional contexts.

Although all three factors affect costs, the second factor has special significance. In the models developed here, the only way in which teaching offers any *potential* for cost savings is through the opportunity to substitute students for other inputs, particularly for physicians. If the production function is such that there is no substitutability (as in Figs. 2(b) and 2(c)), then the use of students necessarily implies higher production costs. Favorable salary levels or attempts to reduce costs through labor-saving procedures could not offset the lost efficiency from having students.

This point is important in evaluating the significance of the empirical results presented in the next section. Although the behavior of VA Radiology departments under analysis may not be representative of that in other departments or in other institutional settings, the production technology used in the VA departments may be representative, at least, of Radiology technology in other kinds of hospitals. As is shown in the next section, substitutability does appear to be a property of some of the VA Radiology production processes, so that the potential for favorable cost effects from teaching does exist.

III. EMPIRICAL ANALYSIS

The primary objective of this section is to illustrate the practical application of the theory presented above. The specific results presented here are of more than casual interest, for they do have a bearing on the question of whether teaching necessarily increases the costs of patient care.

The preceding theoretical analysis shows that the ability to substitute students for nonstudent inputs is a necessary though not a sufficient condition for teaching to reduce the costs of primary production. The results of the VA Radiology analysis suggest that teaching reduces costs for many Radiology outputs, in turn implying substitutability. Since substitutability is a property of the production technology (as opposed to the institutional structure of VA Radiology departments), non-VA Radiology departments using the same technology may also experience cost benefits from teaching. More generally, the observation that teaching reduces costs for some primary outputs in some hospitals is sufficient to refute the view that teaching inevitably leads to higher costs.

The choice of VA Radiology departments for this analysis is based on data availability and some institutional characteristics that simplify the analysis, as described below.

DATA

To conduct an empirical cost analysis based on the models presented above, we require data on costs, primary output levels, and training activities *at the department level.* In this respect, VA data systems are unique in providing detailed departmental data in accessible forms. Moreover, the VA system encompasses a large number of institutionally homogeneous hospitals, widely distributed in patient load, case mix, teaching responsibilities, and geographic location.

The VA data used here concern Radiology departments in 90 General Medical and Surgical Hospitals for fiscal year 1973. The sample contains about 75 percent of all such GM&S hospitals because of the exclusion of those operating in conjunction with Nursing Homes, Pyschiatric Hospitals, Supply Depots, or other service units;[17] the objective of the exclusions is to avoid potential data incomparability due to differences in administrative structure.

Three VA data systems provide the measures of costs, outputs, and training activities of Radiology departments. The AMIS (Automated Management Information System) provides considerable detail in the measurement of Radiology services produced. For each department in the sample of hospitals, the number of patient visits is reported for each of 22 diagnostic procedures, as are the total numbers of patient visits, exposures, and bedside and operating room exams. For therapeutic procedures, both the numbers of individual patients and the numbers of visits are

[17] The sample also excludes hospitals with incomplete departmental data and one hospital whose data appeared to contain a substantial reporting error.

reported in each of six categories; the figures are available separately for procedures performed inhouse and those conducted elsewhere on a fee-for-service basis.

The Trainee Report lists numbers of students and the average length of the training episode for detailed training categories. Four training levels are distinguished: Residents, Interns, Medical Students, and Trainees. For the sample of hospitals, only Residents and Trainees were specifically assigned to Radiology, and for these two categories we computed full-time equivalent students from the data on numbers of students and length of the training episode. Although interns and medical students may rotate through Radiology in some hospitals, it is not possible to determine the actual level of involvement of these students in Radiology from the data at our disposal.

The cost data come from the VA Cost Accounting Report,[18] which lists actual operating budgets for each department in each station. The cost data include salaries of house staff, physicians, and nurses as well as the costs of supplies and purchased services but exclude capital costs; the implications of this omission are discussed below.

The degree of differentiation among VA Radiology departments in costs, production, and teaching activities is shown in Table 1. With respect to teaching, the sample is fairly evenly distributed among four categories: nonteaching departments, departments with Residents but no Trainees, departments with Trainees but no Residents, and departments with both Residents and Trainees. For each category, the table lists average costs, average workload by output category, the average number of full-time-equivalent Residents (RES) and Trainees (TRN), the number of departments in the category, and the proportion of departments in each category operating in hospitals with medical school affiliations. The workload variables were developed for use in the regression analysis, as reported below. The definitions of the variables are as follows:

EASY = sum of output levels of the following diagnostic procedures: skull; chest, single view; chest, multiple view; esophagram cardiac series; abdomen-KUB; obstructive series; skeletal; genitourinary; cholecystogram and cholangiogram; lymphangiogram; and hip pinning.

DIFF = sum of output levels of the following diagnostic procedures: laminagram, bronchogram; angio cardiogram, cardiac catheterization; cerebral, visceral, or peripheral angiogram or catheterization; myelogram; and pneumoencephalogram or ventriculogram;

SPEX = total number of diagnostic procedures performed at bedside or in the operating room;

XRAY1, XRAY2, ISOTOPES, COBALT, OTHER = output levels for therapeutic procedures—i.e., deep X-ray therapy, superficial X-ray therapy, radioisotope therapy, cobalt therapy, and other therapy, respectively.

[18] This report shows cost distributions only for funds allocated to the VA under the Medical Care Appropriation, which covers all but a trivial portion of VA hospital operating budgets, so the omission of funds assigned under other appropriations titles is unlikely to have much effect on our empirical analysis.

Table 1

MEAN DEPARTMENTAL COST AND WORKLOAD BY TEACHING STATUS
(STANDARD DEVIATION IN PARENTHESES)

Variable	Nonteaching	Residents Only	Trainees Only	Both Residents and Trainees
Cost	$258,470 (222,160)	$762,160 (311,580)	$226,200 (130,460)	$757,290 (441,020)
EASY	21,081 (15,763)	48,560 (19,764)	19,071 (10,081)	43,560 (21,128)
DIFF	394.08 (429.90)	1379.6 (786.0)	311.55 (298.29)	1556.3 (1014.0)
SPEX	1176.1 (1214.1)	4803.9 (1841.0)	1056.8 (1077.5)	4403.1 (2094.3)
XRAY1	91.872 (266.21)	244.17 (402.14)	30.455 (63.514)	285.77 (674.93)
XRAY2	8.0256 (20.561)	80.444 (142.83)	— —	29.091 (67.743)
ISOTOPES	.69231 (4.2677)	179.78 (617.94)	83.909 (265.34)	1.7727 (7.6985)
COBALT	667.69 (1703.0)	1220.6 (2024.6)	— —	1559.3 (2442.3)
OTHER	79.615 (446.01)	336.17 (999.75)	— —	926.14 (3951.8)
RES		10.089 (7.5424)		16.455 (10.556)
TRN			2.7455 (2.4824)	7.9591 (7.2860)
SAMPLE	39	18	11	22
% AFFILIATED	28.2	83.3	27.3	95.5

The means and standard deviations[19] of the variables are indicative of their wide dispersion in values, both within the teaching subsamples and for the entire sample of 90 hospitals. Although there is considerable correspondence between output levels and teaching status (for Residency programs, though not for Trainee programs), the teaching subsamples do overlap in output levels. For empirical analysis the overlap is fortunate, as it provides an opportunity to distinguish the cost effects of hospital size from those of teaching status.

The existence of Radiology Residency programs is also closely related to the affiliation status of the hospitals in which the departments are located, though the same cannot be said for Trainee programs. Nevertheless, a number of nonteaching departments are located in affiliated hospitals. We are therefore able to conduct some indicative tests of the effects of nondepartmental teaching on the costs of Radiology production and to distinguish these cost effects from those of Radiology department teaching.

[19] A standard deviation of a variable is the positive square root of the variance of the variable; the variance is the mean sum of squares of the differences between values of the variable and its mean and is a measure of the dispersion of a variable. Thus, a large standard deviation implies considerable variation around the mean.

INSTITUTIONAL CHARACTERISTICS

There are some characteristics of Radiology departments and the VA hospital system that facilitate our cost analysis. Some of the characteristics allow us to use fairly simple formulations of the cost equations, while others mitigate potential statistical problems in the analysis.

First, Radiology departments generally respond to orders placed by other departments or attending physicians and have little internal control over output levels. Therefore, we assume that Radiology output levels are predetermined (i.e., before costs are determined). This permits us to use output levels to "explain" costs; moreover, we can assume that Radiology teaching programs do not affect output levels.

Second, the VA hospital system is centrally administered and monitored. This suggests a tendency for uniformity in the nature (e.g., quality) of a primary output that is produced in different hospitals. Moreover, outputs would tend to be defined in a consistent manner across hospitals. For these reasons, cost differences due to product heterogeneity are likely to be minimal. In addition, wage scales and some purchasing practices are centrally administered in the VA. Although some variability in input prices remains, we can reasonably assume that differences among departments are minimal.

A third institutional characteristic relevant to the analysis is that all VA hospitals have the same patient-care mandate (basically, to treat veterans, their families, and surviving dependents). For hospitals that produce a certain service, such as cobalt therapy, there are not likely to be vast differences in the kinds of patients receiving the service. Therefore, we expect small cost effects due to differences in patient characteristics.

Fourth, although different hospitals produce different sets of Radiology outputs, production interdependencies are not likely to have large cost implications. Many Radiology therapy outputs are highly specialized, requiring particular labor skills and capital equipment in production. While this may be less true for diagnostic procedures, a preliminary analysis of the data showed that these outputs vary together; there is little difference in the mix of diagnostic services produced, so there is likely to be little difference in the extent to which economies due to production interdependencies are exploited at each overall output level.

The capital-allocation system in the VA is of special importance in this analysis. Capital replacement is conducted according to a schedule that applies to each type of equipment in all hospitals, while capital acquisition allocations are based on "need." To the extent that "need" is defined by output levels, all Radiology departments producing a given output level would tend to have access to the same capital inputs. This is important in the present context because capital costs are omitted from our cost data. However, if a given output level is produced using very similar capital inputs throughout the VA, then capital costs at each output level would also tend to be equal across hospitals and would vary with output in a prescribed manner. Although we cannot describe the total cost differences between teaching and nonteaching departments, our data do allow us to estimate the effects of teaching on noncapital (especially labor) costs, and this information is sufficient to consider whether there is substitutability of students for physicians.

The final relevant institutional characteristics concern teaching constraints. In Radiology, teaching programs generally require a broad set of student experiences in providing various outputs. From our data, we are unable to determine how much teaching is conducted with respect to each type of departmental output. However, to the extent that teaching programs do require a fairly specific assortment of tasks for each student, the pattern of student involvement will not differ extensively among hospitals. Based on this view, our empirical analysis assumes that when the number of students is, say doubled, then the involvement of students in each production process is approximately doubled.

The question remains as to how the total number of students is determined; this question is important because if the level of student inputs is always at the cost-minimizing level (i.e., if total student inputs are endogenous), then an estimation procedure that uses numbers of students as an explanatory variable may yield biased and inefficient coefficient estimates.[20] Although the present study does not include specific assumptions about how student input levels are chosen in VA Radiology departments, we do assume that the levels are predetermined and not subject to change during the period under analysis.

EMPIRICAL COST EQUATIONS

The total department cost equations to be estimated consist of combinations of simpler specifications of costs and teaching effects for individual outputs. Here, we explain the underlying components of the estimating equations.

For a single output produced in the absence of teaching, one of the simplest cost specifications that might be postulated is linear:

$$c = a + bQ + e, \qquad (4)$$

where c is the cost of producing the output, Q is the quantity produced, a and b are cost parameters, and e is an error term. The specification implies that costs would be equal to a at zero output (a is the fixed cost of producing Q), and costs would rise by a constant increment, b, for each additional unit of Q. Thus, b is not only the cost of producing the last unit of Q (the marginal cost of Q) but is also the average variable cost per unit for all units of Q.

If we postulate that the average cost of Q varies with output levels, say, because of economies or diseconomies of scale, then Eq. (4) should be modified. A different specification that is useful in our empirical analysis is a cubic cost equation:

$$c = a' + b'Q + dQ^2 + fQ^3 + e', \qquad (5)$$

where d and f are two additional cost parameters to be estimated, and the primes on a, b, and e are used to distinguish the parameters in (5) from those in (4). In Eq. (5), neither marginal nor average costs are constant and, for most output levels, marginal and average costs are not equal.[21] The difference between Eq. (4) and Eq.

[20] Notably, if student inputs are always at their cost-minimizing level and if our assumptions about input prices, similarity of technology across hospitals at each output level, etc. are valid, then there would be severe multicollinearity between output levels and student inputs. However, preliminary empirical analysis showed that only about 50 percent of the variance in Resident inputs and 30-35 percent of the variance in Trainee inputs can be "explained" by output levels.

[21] In Eq. (5), average costs are $c/Q = a'(1/Q) + b' + dQ + fQ^2$, while marginal costs are $dc/dQ = b' + 2dQ + 3fQ^2$.

(5) is illustrated by comparing the cost curves for the two equations as illustrated in Figures 3(a) and 3(b).

Under the assumption that the production processes for individual Radiology outputs are mutually independent, the cost equation for an entire department consists of the sum of the cost equations for the individual outputs. For example, if the costs of output Q_1 are given by Eq. (4) and the costs of output Q_2 are given by Eq. (5), the total departmental cost equation might be written:

$$C = \alpha_0 + \alpha_1 Q_1 + \alpha_2 Q_2 + \alpha_2'(Q_2)^2 + \alpha_2''(Q_2)^3 + \epsilon, \tag{6}$$

where $\alpha_0 = a + a'$,
$\alpha_1 = b$,
$\alpha_2 = b'$,
$\alpha_2' = d$,
$\alpha_2'' = f$,
$\epsilon = e + e'$,
and $C =$ total departmental costs.

A total cost equation based on summing individual output cost equations as in Eq. (6) forms the basic cost equation to be estimated. Variables to permit us to estimate teaching effects are then added to the basic equation.

To simplify the analysis of teaching effects, we approximate teaching production by assuming that a teaching program consists of individual training tasks, each produced jointly with a single primary output. This permits us to analyze separately the cost effects of teaching for each primary output. Moreover, we assume that teaching effects for the two types of teaching programs (Residents and Trainees) are mutually independent; thus, we may separately consider the specifications for the two types of teaching.

As stated above we postulate that total student inputs are predetermined. This implies that costs may differ with student inputs, holding output constant. From the analysis in Section II, it is clear that costs may either rise monotonically or fall and then rise as student inputs increase, output constant. Although a full specification of teaching effects would allow a nonlinear relationship between costs and levels of student inputs, preliminary empirical analysis suggested that a linear relationship provides a good approximation.[22] The relationship between various linear approximations and underlying curvilinear cost effects is illustrated in Fig. 4.

To estimate the cost effects of teaching, therefore, we use a specification of the cost equation that allows the cost parameters (e.g., a and b in Eq. (4)) to differ with the level of student inputs. This is achieved by including interaction terms wherein, for example, each of the variables in Eq. (4) also appears as a variable multiplied by the number of students.

For a single student category, Eq. (4) would become:

$$c = a + a_n N + bQ + b_n N \cdot Q + u', \tag{7}$$

where N is the number of students. The coefficients a_n and b_n provide estimates of the difference in fixed and marginal costs of Q between teaching and nonteaching

[22] Moreover, the small size of our sample prohibits further complexity in specification because of the substantial multicollinearity that arises among interaction terms involving higher powers of the student input variables.

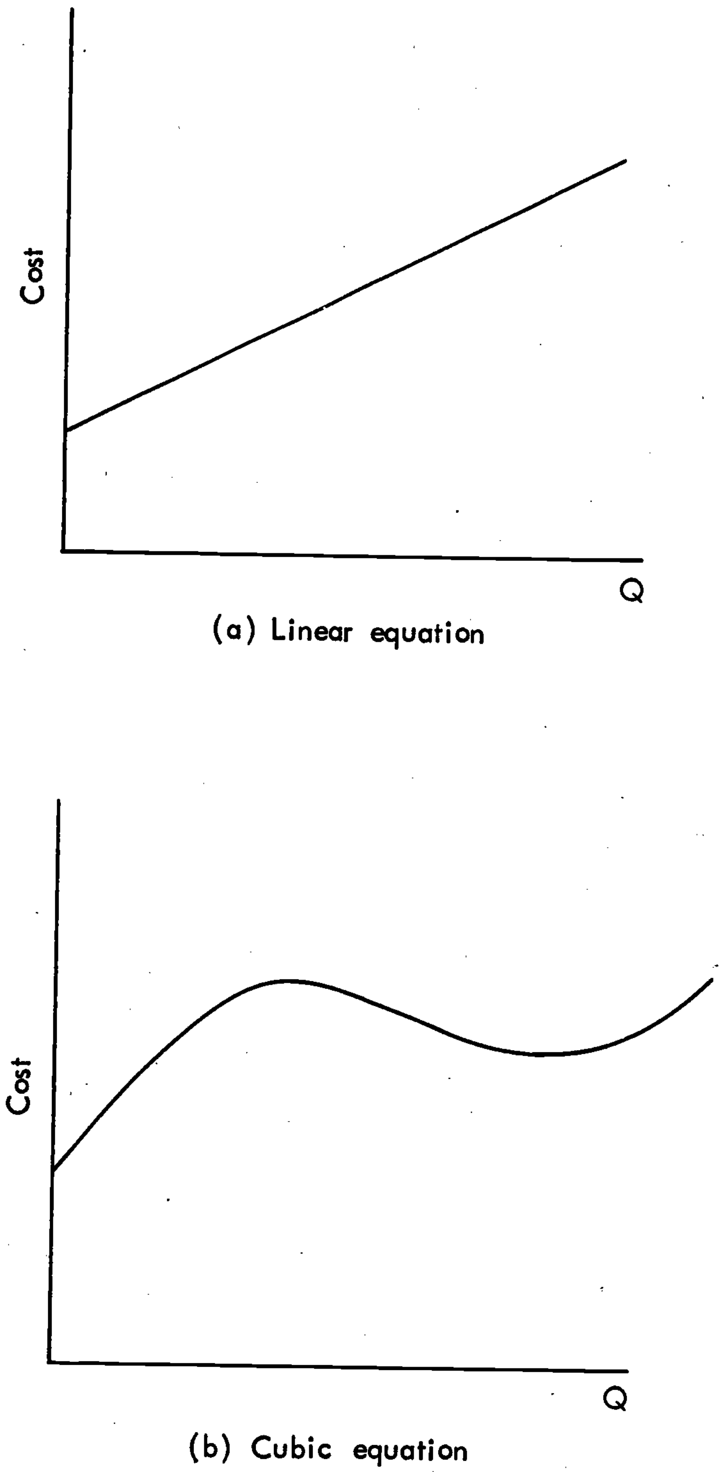

Fig. 3—Alternative cost specifications

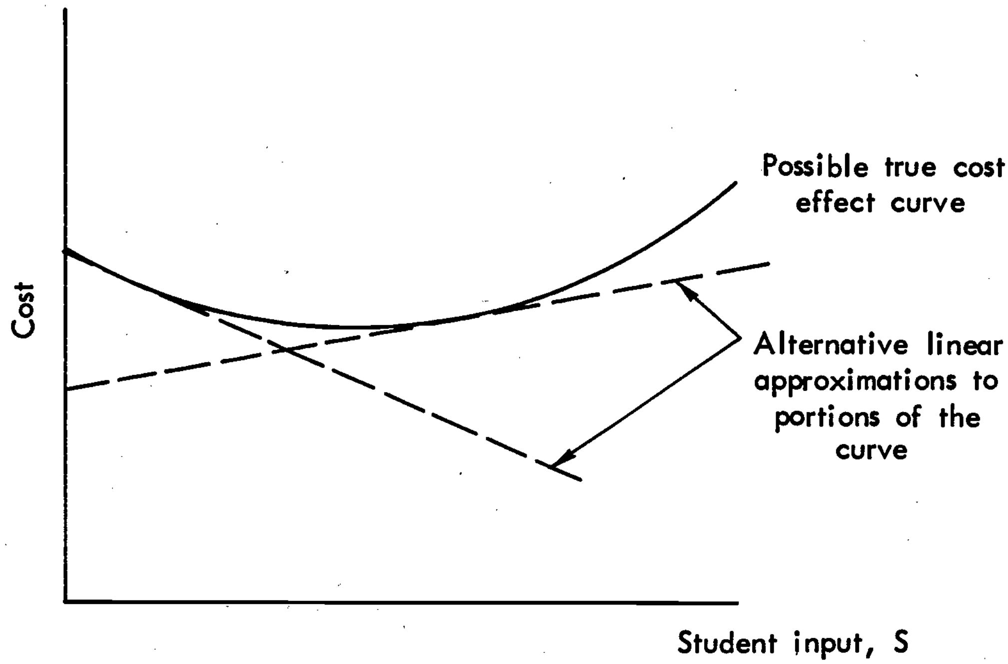

Fig. 4—Linear approximations to curvilinear cost effects

departments on a per-student basis. Since teaching constraints can result in either higher or lower costs, there are no *a priori* expectations about the sign of the total cost effect. For VA Radiology departments, interaction terms would be specified for each of two teaching categories, Residents and Trainees.

Just as the basic departmental cost equation (Eq. (6)) is derived by summing the individual output cost equations the full departmental cost equation is derived by summing the individual-output, teaching-effect equations. For example, the full specifications for two outputs with one student category would be:[23]

$$C = \alpha_0 + \alpha_1 Q_1 + \alpha_2(Q_2) + \alpha_2'(Q_2)^2 + \alpha_2''(Q_2)^3 + \gamma N + \gamma_1 N Q_1 + \gamma_2 N Q_2 + \gamma_2' N(Q_2)^2 + \gamma_2'' N(Q_2)^3 + \epsilon'. \tag{8}$$

With two student categories and more than two outputs, the estimating equation becomes quite lengthy. In addition, in some specifications we include variables to reflect the possible cost effects of nondepartmental teaching. We assume, however, that any nondepartmental teaching effects appear as differences in department fixed costs, so interaction terms are not used for specifying nondepartmental teaching effects.

THE VARIABLES

Several measures of output and student inputs were used in preliminary analy-

[23] Note that the total number of students, N, appears in the interaction terms for each output. Under the assumption that a constant proportion of student inputs is used in each production across hospitals, the estimates of the γ-coefficients will automatically include the appropriate proportionality factors.

sis. Some outputs are produced at very low levels and in just a few departments; since the cost coefficients of these outputs were consistently small and statistically insignificant, the variables were omitted from the equations reported here.

Several of the diagnostic outputs are produced in nearly equal proportions across departments. Prelimininary analysis indicated that a regression equation could not distinguish among the costs of these outputs. Therefore, we formed two composite variables, heuristically labeled EASY and DIFF. Each is the sum of output quantities for services with equal ratings according to the California Relative Value Unit scales.[24] The EASY outputs have low scale values and, by definition of the RVU scale, should be expected to have low production costs. The DIFF outputs have high scale values and should have high costs.

The student input variables and the various output variables are as defined with respect to Table 1, above. The student inputs are measured in terms of full-time equivalents to control for differences among hospitals in the training period; this correction is more important for Trainees than for Residents because most Residents are in full-year programs.

The variables for nondepartmental teaching are NOTH, the number of students outside the Radiology department, and AFFIL, a dummy variable equal to one if the department is in an affiliated hospital. When both of these variables are included, collinearity prevents estimation. Therefore, we report only the results in which each of the alternative variables is used alone.

EMPIRICAL RESULTS

Table 2 presents the results for several specifications of the cost equations.[25] For comparative purposes, Eq. (1) in the table shows the results from the basic cost equation (with no teaching variables) for the sample of nonteaching hospitals. In principle, a correct specification of teaching effects when estimated for the full sample should yield the same set of coefficients for the basic output variables as is estimated in Eq. (1); in other words, the teaching-effect variables should fully account for cost differences between teaching and nonteaching hospitals. Nevertheless, some discrepancies in the estimated coefficients of outputs between the nonteaching and full samples are to be expected because the nonteaching sample is rather small and fairly homogeneous in outputs and costs. If the estimating equation is correctly specified, the larger sample would generally produce more precise coefficients for the basic output variables.

Equation (2) uses the same specification as Eq. (1) but is calculated from the entire sample of departments. If teaching had no effect on costs, the results from Eq. (2) would provide estimates of the cost per unit of producing each output in all hospitals.

Equations (3) through (5) include the teaching effect variables in estimation for the full sample of hospitals. Whereas Eq. (3) omits the nondepartmental teaching

[24] *1969 California Relative Value Studies, Fifth Edition*, prepared by the Committee on Relative Value Studies, California Medical Association, San Francisco, 1972.

[25] We also experimented with an alternative regression specification. In the alternative, unit costs for each output are permitted to differ between teaching and nonteaching departments, but among teaching departments the costs are assumed to be independent of the number of students. Because this specification produced results on the whole similar to those of Eqs. (3)-(5), we have not included the results here.

Table 2

COST EQUATIONS FOR VA RADIOLOGY DEPARTMENTS
(T-VALUES IN PARENTHESES)[a]

Variables	Eq. (1) Nonteaching Sample	Eq. (2) Full Sample	Eq. (3) Full Sample	Eq. (4) Full Sample	Eq. (5) Full Sample
I. OUTPUTS					
EASY	4.542 (4.060)**	4.870 (3.376)**	5.005 (3.381)**	5.053 (3.370)**	4.930 (3.220)**
DIFF	281.2 (2.219)**	42.39 (.3806)	325.2 (2.020)**	329.7 (2.025)**	317.8 (1.919)*
$DIFF^2$	−.1257 (−.4880)	−.1883E-01 (−.2682)	−.2061 (−1.367)	−.2066 (−1.361)	−.2006 (−1.303)
$DIFF^3$	.5264E-05 (.0400)	.2200E-05 (.1661)	.4007E-05 (1.018)	.3985E-04 (1.005)	.3919E-04 (.9834)
SPEX	5.174 (.3175)	63.14 (3.519)**	21.66 (1.156)	22.14 (1.169)	20.94 (1.092)
XRAY1	70.85 (2.198)**	69.76 (1.385)	30.34 (.5774)	31.65 (.5960)	34.18 (.6129)
XRAY2	−701.2 (−1.508)	578.9 (2.426)**	453.2 (.9876)	453.6 (.9813)	452.1 (.9775)
ISOTOPES	−5196. (−1.594)	−63.92 (−1.263)	545.5 (1.621)	553.3 (1.628)	533.4 (1.553)
COBALT	75.66 (7.161)**	60.27 (6.370)**	44.74 (5.627)**	45.05 (5.581)**	45.22 (5.443)**
OTHER	4.510 (.2084)**	25.16 (2.451)**	38.27 (2.226)**	38.92 (2.231)**	38.54 (2.218)**
II. RESIDENT INTERACTIONS			(MULT.)	(MULT.)	(MULT.)
EASY X RES			−.4247 (−2.368)**	−.4260 (−2.358)**	−.4216 (−2.326)**
DIFF X RES			−21.532 (−1.202)	−21.64 (−1.199)	−20.92 (−1.145)
$DIFF^2$ X RES			.9118E-02 (.7018)	.9092E-02 (.6947)	.8637E-02 (.6509)
$DIFF^3$ X RES			−.1382E-05 (−.4912)	−.1371E-05 (−.4836)	−.1300E-05 (−.4547)
SPEX X RES			8.653 (4.896)**	8.689 (4.870)**	8.714 (4.834)**
XRAY1 X RES			−29.17 (−4.897)**	−29.42 (−4.860)**	−29.55 (−4.726)**
XRAY2 X RES			32.81 (1.339)	33.05 (1.338)	33.24 (1.341)
ISOTOPES X RES			−59.69 (−1.752)*	−60.67 (−1.760)*	−58.52 (−1.684)*
RESIDENTS			8873 (1.038)	9136 (1.056)	8413. (.9493)

Table 2 (CONTINUED)

Variables	Eq. (1) Nonteaching Sample	Eq. (2) Full Sample	Eq. (3) Full Sample	Eq. (4) Full Sample	Eq. (5) Full Sample
III. TRAINEE INTERACTIONS			(MULT.)	(MULT.)	(MULT.)
EASY X TRN			.5992 (2.187)**	.5981 (2.167)**	.5949 (2.149)**
DIFF X TRN			−51.739 (−1.557)	−51.79 (−1.549)	−52.11 (−1.555)
$DIFF^2$ X TRN			.34922E-01 (1.396)	.3491E-01 (1.385)	.3547E-01 (1.400)
$DIFF^3$ X TRN			−.60728E-05 (−1.156)	−.6062E-05 (−1.145)	−.6186E-05 (−1.163)
SPEX X TRN			−6.279 (−1.736)	−6.309 (−1.731)*	−6.348 (−1.735)*
XRAY1 X TRN			50.64 (6.187)**	50.76 (6.149)**	50.97 (6.083)**
XRAY2 X TRN			−103.9 (−1.276)	−106.3 (−1.290)	−106.5 (−1.284)
ISOTOPES X TRN			−119.8 (−1.595)	−121 6 (−1.602)	−117.2 (−1.528)
TRAINEES			4673 (.3945)	4908. (.4105)	4767. (.3990)
IV. NONDEPT. TEACHING					
NOTH				−14.228 (−.312)	
AFFIL					6742. (.2199)
CONSTANT	.3840E 05 (2.118)**	.5000E 05 (1.529)	.2616E 05 (1.015)	.2635E 05 (1.015)	.2743E 05 (1.031)
CORRECTED R^2	.9699	.8836	.9569	.9562	.9562
STANDARD ERROR	.3904E 05	.1348E 06	.8202E 05	.8263E 05	.8267E 05
SAMPLE SIZE	39	90	90	90	90

* t-value significant at 10 percent (two-tailed test).

** t-value significant at 5 percent (two-tailed test).

[a] Department variable is total annual noncapital costs of VA Radiology departments.

variables, Eqs. (4) and (5) include NOTH and AFFIL, respectively. As is readily apparent from the table, the coefficients of nondepartmental teaching variables lack statistical significance, and the inclusion of such variables has little effect on the other estimated coefficients; neither levels of student inputs in other departments nor hospital affiliation status appear to affect Radiology costs. For this reason, in further discussion of the results, we focus our attention on Eq. (3).

Since the estimating sample contains just 90 departments with many outputs, the cost equations reported in the table reflect some limitations in specification. Aside from grouping outputs to form the composite variables (EASY and DIFF) and excluding some output measures with insignificant coefficients, we found it necessary to limit the consideration of nonlinearity in costs to that associated with the DIFF variable. Moreover, we eliminated the teaching interaction terms for COBALT and OTHER. In each such case, the decision to reduce the number of coefficients to be estimated reflects information obtained in preliminary data analysis. The results reported are, we believe, indicative of the results from more complete specifications, while the statistical significance and economic interpretation of the results is improved. Nevertheless, it may be inadvisable to place considerable reliance on the precise cost estimate implied by any one coefficient. Instead, each equation should be considered in its entirety.

There are several ways to evaluate the equations. An important indicator is goodness-of-fit, as measured by the corrected R^2 for each equation.[26] Equation (3) "explains" over 95 percent of the cost variability among departments; Eq. (2) explains 88 percent.

A second criterion is the explanatory power of the teaching interaction terms as indicated by F-tests for the set of all Resident or all Trainee interactions. The values of the F-statistics for Eq. (3) are shown in Table 3; both values are highly significant (at better than the 1 percent confidence level).

Table 3
F-VALUES FOR STUDENT INTERACTION TERMS IN EQ. (3)

Residents, all interactions[a]	10.417
Trainees, all interactions[a]	9.001

[a]With (9,62) degrees of freedom.

A third criterion is the economic plausibility of the estimated coefficients. In these cost equations, the marginal costs of each type of output should always be positive for either teaching or nonteaching departments. For nonteaching departments, the marginal costs are given by the coefficients estimated for the basic output variables. (For example, in Eq. (3), the estimated marginal cost of an EASY output is approximately \$5.00.) Each of the equations (1) through (5) yields one or more negative signs on the basic output coefficients, but in each such case the coefficient

[26] The corrected R^2 is the proportion of the variance of the dependent variable (departmental costs) explained by the estimated equation. The R^2 is corrected to take account of the sample size and the number of explanatory variables used in estimation.

lacks statistical significance.[27] For teaching departments, the marginal cost of an output is the sum of the basic and interaction coefficients. (For example, in a department with one Resident, the marginal cost of an EASY output as indicated by Eq. (3) would be 5.0050 + (−.4247) = $4.5803). In Eq. (3) all such marginal costs are positive.

A further economic criterion for evaluating the equations concerns the marginal costs for DIFF. Since the equation permits variation in DIFF marginal costs over the DIFF output range, it is necessary to investigate the shape of the DIFF cost curve as indicated by all the DIFF coefficients taken together. In general, the cubic specification allows costs for DIFF to fall over a range, as was shown in Fig. 3. Some decline in costs (i.e., negative marginal costs) over a range is observed in Eqs. (3) through (5), but the extent of decline is modest. The question is whether any decline is plausible on economic grounds.

In these equations we observe only noncapital costs, so the observation that these costs decline as output increases is not inconsistent with the reasonable presumption that it must cost more to produce more. Nevertheless, it is unusual to observe a decline in the use of even a subset of inputs as output increases. A possible explanation for the behavior observed in our data is that the technology used in producing DIFF changes as output increases, perhaps through increased automation so that labor input declines. This may pose some problem with respect to our empirical cost specification, though the problem is not severe if the same changeovers in technology are available to nonteaching as well as teaching hospitals; if so, the equations may accurately trace out the cost pattern as DIFF output increases.

According to the foregoing criteria, the teaching interaction equation (Eq. (3)) yields plausible results and fairly good statistical properties. We now turn to the implications of the results for evaluating teaching effects.

From the Resident interaction terms in Eq. (3), it appears that the use of Residents reduces production costs for all output variables except SPEX and XRAY2. Moreover, the cost increase for XRAY2 is not statistically significant. While the cost increase for SPEX is statistically significant, the higher cost may not be attributable to teaching. As noted earlier, the SPEX variable measures the number of times diagnostic Radiology procedures are produced outside the department (i.e., at bedside or in the operating room). The kinds of procedures performed and the severity of the cases in which special exams are used can vary substantially among hospitals, and the cost of doing a special exam may reflect these underlying factors. If departments with Residents tend to treat cases or perform Radiology services that make special exams more costly, the cost effect we estimate may not be attributable to departmental teaching. We shall return to this issue when we calculate overall cost effects, below.

From the Trainee interaction terms in Eq. (3), it appears that the use of Trainees in production reduces costs for all outputs except those measured by the variables EASY and XRAY1. (In both cases, the estimated coefficients are highly significant statistically.) Further, the estimated cost effects for Trainees are opposite of those for Residents for four of the six output variables: EASY, SPEX, XRAY1, and XRAY2. The cost differences may reflect differences in the nature of Trainee and

[27] In the table, the t-statistic of each coefficient is indicated in parentheses. If the t-statistic is greater than 1.96, the coefficient is nonzero with at least 95 percent confidence; if the t-statistic is between 1.65 and 1.96, the coefficient is nonzero with 90-95 percent confidence.

Resident training or differences in the amount of medical education embodied in Trainees and Residents when they enter hospital-based training. Alternatively, the apparent differences may be an artifact of underlying differences in the types of departments that train Residents or Trainees. One such difference, apparent in Table 1 above, is scale of production; thus, for some outputs, the TRN and RES interactions may be acting as proxies for scale differences, and the estimated coefficients may reflect cost effects of scale rather than teaching. Notably, the equations permit costs to vary with scale of output of DIFF procedures; observe that in this instance both the Trainee and Resident interactions imply negative cost effects.

A final comment on the results presented in Table 2 concerns the coefficients of the RES and TRN variables in Eq. (3) (the numbers of full-time equivalent Residents and Trainees). Although not statistically significant (possibly because of high correlations between these variables and the interaction terms), the coefficients of these variables in Eq. (3) are both positive, indicating higher costs per Resident and per Trainee. This finding is not inconsistent with an overall result that teaching reduces cost. The reason is that these coefficients represent the cost of increasing an input to production, which, other things equal, necessarily implies higher costs.[28] In fact, the estimated cost increase should be approximately equal to the salary levels of students, for this is the amount by which costs would increase if student inputs increased and there were no change in output or other inputs. This point deserves emphasis because it is an important instance in which the present analysis departs from approaches used in some previous hospital cost studies. In the models used here, students are explicitly treated as inputs to production, which automatically suggests that positive coefficients on student input variables are to be expected regardless of whether teaching increases or decreases production costs. This is in stark contrast to previous studies[29] that use numbers of students as measures of teaching *output* and, consequently, interpret positive coefficients as evidence of higher costs due to teaching. Our models suggest that this interpretation may be erroneous.

Having examined the detailed empirical estimates of teaching effects, we now consider overall estimates of teaching effects on Radiology departmental costs. Estimates of the effects from the coefficients of Eq. (3) are presented in Table 4.[30] The table shows the predicted noncapital cost effects per Resident or Trainee computed for each of four output mixes. The output mixes used to make the computations are the average annual output levels of the four teaching subsamples of departments described in Table 1 above. Table 4 shows the average change in departmental cost from adding one Resident or one Trainee, given the departmental output mix. In addition, it shows the estimated effect for each output as well as the total effect exclusive of the effects estimated for SPEX.

[28] Alternatively, the coefficients can be viewed as intercept terms. Since cost-equation intercepts show what costs would be if output were zero, it is clear that the student intercepts should be positive; if students were used as input when output is zero, costs would be positive.

[29] E.g., Carr and Feldstein, "The Relationship of Cost to Hospital Size."

[30] Since the estimating equation is not based on a fully specified production model, the cost figures should not be extrapolated much beyond the range of student input levels observed in the estimating sample. Although the estimates would vary linearly with the numbers of students, it is almost certainly not true that, say, ten times the estimated savings would be achieved by using ten times as many students. Nevertheless, the figures do indicate that VA Radiology departments are generally operating in a range of student input levels that generates cost savings.

Table 4

ESTIMATED COST EFFECTS OF TEACHING, PER RESIDENT AND PER TRAINEE, COMPUTED AT SAMPLE MEANS FOR FOUR SAMPLES, USING COEFFICIENTS FROM EQ. (3)[a]

Estimated Cost Effects	Nonteaching		Residents Only		Trainees Only		Both	
	Resident	Trainee	Resident	Trainee	Resident	Trainee	Resident	Trainee
Total (per student)	$474.1	$−1,701.5	$−1,376.5	$−34,782.5	$−1,844.0	$−11,958.7	$4,350.7	$−4,465.8
By variable								
EASY	−8,953.1	12,631.7	−20,623.4	29,097.2	−8,099.5	11,427.3	−18,499.9	26,101.2
DIFF	−7,164.7	−15,357.1	−15,980.1	−20,858.1	−5,865.1	12,913.3	−16,635.2	−18,829.1
SPEX	10,176.8	−7,384.7	41,568.1	−30,163.7	9,144.5	−6,635.6	38,100.0	−27,647.1
XRAY1	−2,679.9	4,652.4	−7,122.4	12,364.8	−888.4	1,542.2	−8,335.9	14,471.4
XRAY2	263.3	−833.9	2,639.4	−8,358.1	—	—	954.5	−3,022.6
ISOTOPES	−41.3	−82.9	−10,731.1	−21,537.6	−5,008.5	−10,052.3	−105.8	−212.4
INTERCEPT	8,873.0	4,673.0	8,873.0	4,673.0	8,873.0	4,673.0	8,873.0	4,673.0
Total minus SPEX interaction effects	−9,702.7	5,683.2	−42,944.6	−4,618.8	−10,988.5	−5,323.1	−33,749.3	$23,181.5

[a]Projected effect on cost of adding one Resident or Trainee while producing the mean level of Radiology outputs for hospitals in each category.

The results indicate that total departmental costs would be reduced by adding a Trainee for any of the four output mixes. Adding a Resident, however, would reduce total costs only for the typical output mix of departments with Residents only and Trainees only. The results for total costs contrast sharply with the results for costs exclusive of those assoicated with the SPEX variable. As shown in the last line of the table, the partial cost effects per Resident are negative for all four output mixes, while the partial cost effects for Trainees are negative only for the departments with Residents only and Trainees only. Clearly, the SPEX interaction coefficient plays a major rôle in determining the sign of the total cost effects. Since the interpretation of the coefficient is subject to question, as we indicated earlier, the estimated cost effects for the remaining departmental outputs may provide a preferable basis for drawing conclusions about how teaching affects production costs.

CONCLUSIONS

In the introduction for this section we suggested that an analysis of VA Radiology costs is valuable both to illustrate the use of the models developed here and to obtain information on whether teaching can lead to reduced noncapital costs. Although a larger data base would contribute to the conclusiveness of the present findings, there appear to be cost savings in producing several outputs associated with teaching in VA Radiology departments. Moreover, some cost savings are observed even when scale effects are taken into account, as shown by the results for the DIFF output variables. If, as our models suggest, these cost savings reflect substitution of students for physicians, savings opportunities may exist not only in other departments within the VA but in non-VA departments as well.

IV. IMPLICATIONS OF THE RESEARCH

A complete analysis of the effect of teaching on hospital costs requires putting together a number of pieces in a large and complex puzzle: Would a given patient receive the same kind of treatment in teaching and nonteaching hospitals? If not, what are the nature and source of the differences? Do any differences derive specifically from teaching activities, or are the differences artifacts of the tendency for teaching to occur in larger, better equipped hospitals? If treatments differ, are consequent cost differences justified by differences in the "quality" of care, however defined? If the teaching and nonteaching hospitals were to provide the same kind and quality of care, would there nevertheless be cost differences? If so, would costs be higher or lower, and by how much? Finally, who should pay for any differences in costs?

The present study has brought economic analysis to bear on a single piece of the puzzle: What is the effect of using students in production on the costs of providing the component services used in treating patients? The answer to this question would have an important bearing on the question of whether costs of patient care in teaching and nonteaching hospitals would differ even if the same kinds of treatment were provided. We have been concerned not only with measuring cost differences but with using economic theory to examine how and why such differences arise. Thus, the objectives of our analysis included developing sound theoretical bases for empirical research as well as obtaining empirical results.

The models of Section II show how teaching can affect primary production costs and demonstrate that the nature of teaching effects depends on the values of production function parameters, on student and physician salary levels, and on the decisionmaking objectives of hospitals. As a result of this analysis, it is clear that teaching effects can differ among departments within a given hospital and among hospitals for a given department. Moreover, the models lay a foundation for the empirical analysis of teaching effects in alternative hospital and departmental settings. Finally, by making explicit the nature of cost factors omitted from the models,[31] the theoretical analysis identifies avenues for future cost research.

An important implication of the models is that generalizing from one institutional context to another is perilous. Therefore, the results obtained from applying the models to any single institutional context are inconclusive. For this reason, our use of VA data may be particularly troublesome to policymakers concerned with costs in non-VA hospitals. However, from this viewpoint, a significant feature of our theoretical analysis is that it also indicates areas in which some generalizations might be appropriate. Specifically, the models suggest that, other things equal, teaching can permit cost reductions in primary production only if students can be substituted for other inputs. As we argued in Section III,

[31] In particular, we have avoided considering differences in the quality of products and services, differences among hospitals in input prices, differences in the patients to whom the products and services are administered, and differences in the extent to which the mix of products produced by a department might affect the costs of the individual products. Moreover, we have bypassed the issue of how the levels of output of the products and services are determined (how the use of products in treatment is determined).

substitutability is a characteristic of the production technology rather than institutional behavior and thus is likely to be generalizable from one institutional context to another. If there are cost reductions from teaching in VA Radiology departments, as our empirical results indicate, then there is substitutability in Radiology production, and there is likely to be an opportunity for cost reductions from teaching in Radiology departments in non-VA hospitals as well.

The observation that VA departments generally take advantage of the opportunity to reduce costs does not imply that non-VA departments also behave in this manner. In particular, in hospitals that use fee-for-service rather than staff physicians, substitutability may not be fully exploited. However, the cost of physician services in a fee-for-service context may be higher than in the case of the VA physician staff. If so, and if student salaries are not much different in the two settings, even low levels of substitution of students for physicians would tend to offer even greater economies in non-VA Radiology departments than are observed in the VA.

It is our hope that the empirical applicability of the new cost analytical methodology illustrated here will contribute to better and more detailed data collection so that future research can address the questions left unanswered here. Five particularly desirable extensions of the research that would be facilitated by obtaining more data are (1) to estimate teaching effects when capital costs are included; (2) to estimate how teaching effects vary with the level of student inputs so that cost-minimizing levels of student inputs could be identified; (3) to investigate departments other than Radiology, particularly those less capital intensive and whose outputs may be more difficult to measure (such as Medicine or Surgery); (4) to examine departments in other institutional settings (in non-VA hospitals) in order to determine whether cost savings are observed outside the VA; and (5) to examine patterns of treatment in order to determine how differences in the patterns affect costs in teaching and nonteaching hospitals. From analyses such as these, policymakers may obtain the knowledge necessary to design policies that provide for an equitable distribution of the costs of teaching and that offer incentives for more efficient hospital production in general. In the interim, the present analysis has been designed to clarify the process by which hospital costs are determined and to provide insight into one step in that process.