clinical uses of CT scanning, but also in the impact of this new technology on the practice of medicine. Interestingly, almost all of the studies of the economics of CT scanning have been authored by physicians or scientists without major collaboration with economists.

Judging by the quantity of published research, one would surmise that the state of the art of economic evaluation of diagnostic procedures—CT scanning, in particular—is well advanced. In fact, the opposite is true. The studies of the cost effectiveness or economic benefit of CT scanning reveal major conceptual and methodological weaknesses that not only mitigate these particular studies' value, but also cast doubt on the overall feasibility of conducting economic evaluations of diagnostic procedures.

The purpose of this case study is to explore the feasibility of economic evaluation of diagnostic procedures. Several questions are addressed. To what extent can cost-benefit analysis (CBA) and its derivative, cost-effectiveness analysis (CEA)—the cornerstones of economic evaluation methodology—be applied to diagnostic procedures? What, if any, methodological and conceptual obstacles to performing such analyses are there? How useful are the results of such analyses?

CBA and CEA are methods to assist in alloeating scarce resources among alternative uses, These methods were developed primarily to evaluate large public-sector investments such as highways, dams, and airports. When applied to diagnostic procedures, they are intended to provide information on two related questions: 1) Under what circumstances should the procedure be performed? and 2) How much investment in capacity to perform the procedure is justified? The answer to the second question rests on thorough study of the first, for only by knowing when a procedure should be performed can one assess how much investment in capacity is justified.

The fundamental argument of this case study is that the conceptual, methodological, and data problems inherent in answering the first question (i.e., when should a given diagnostic procedure be used?) often create such inaccurate and unreliable results that CEA/CBA is generally not worthwhile. In only a few situations (to be enumerated later) is such economic evaluation likely to be particularly illuminating and therefore useful to medical decisionmakers.

Such **a** pessimistic prognosis for the application of CBA and CEA needs to be explained and supported with evidence. In this case study, therefore, we begin with an idealized model of economic evaluation of diagnostic procedures and then use this model to explore the implications of problems that occur in attempts to apply it. Some typical second best approaches, designed to circumvent these problems, are then described, with particular emphasis on the use of these approaches in the evaluation of CT scanning.

The economic evaluations of CT scanning include three general analytic approaches: 1) good faith but limited attempts to apply the principles of economic evaluation, 2) estimates of the impact of CT scanning technology on health care expenditures, and 3) analyses of the amount and location of CT scanning capacity required to meet a predetermined level of demand. Each of these approaches is assessed with respect to its limitations as valid economic evaluation and the particular methodological weaknesses that raise questions as to the ultimate feasibility and usefulness of economic evaluation.

CBA AND CEA: THE THEORETICAL IDEAL

The purpose of CBA and CEA is to help decisionmakers determine the best allocation of resources among possible alternative uses. CBA is used to measure the difference between the value of all benefits resulting from an activity, both at present and in the future, and the costs. If this difference, or net social benefit, is positive, the activity would be said to be worth its costs, and the decision should be made to allocate scarce resources (labor, capital, etc.) to producing the benefits.

Straightforward as this decisionmaking tool is, the benefits accruing from an activity, particularly those undertaken in the public sector, are often difficult even to identify, much less to value. Because CBA requires enumeration and valuation of all significant benefits, analysts have derived the seemingly simpler technique of CEA. Here, a single measure of effectiveness is designated, and the ratio of cost to effectiveness guides resource allocation decisions among competing alternatives.

Applying these principles to medical procedures, CBA would enumerate and place a value on all benefits (both positive and negative) derived from performing a procedure on patients with a specified set of conditions and would compare those benefits to the cost of performing the procedure. The resulting net social benefit would indicate whether the procedure should be performed under the specified conditions. In CEA, a measure of procedure effectiveness would be designated, and the ratio of that single measure to cost would be the critical item for resource allocation. Lives saved, life-years saved, quality-adjusted life-years saved, disability-days saved, and age-adjusted disability days saved are measures of effectiveness often chosen in studies of health care programs *(43).*

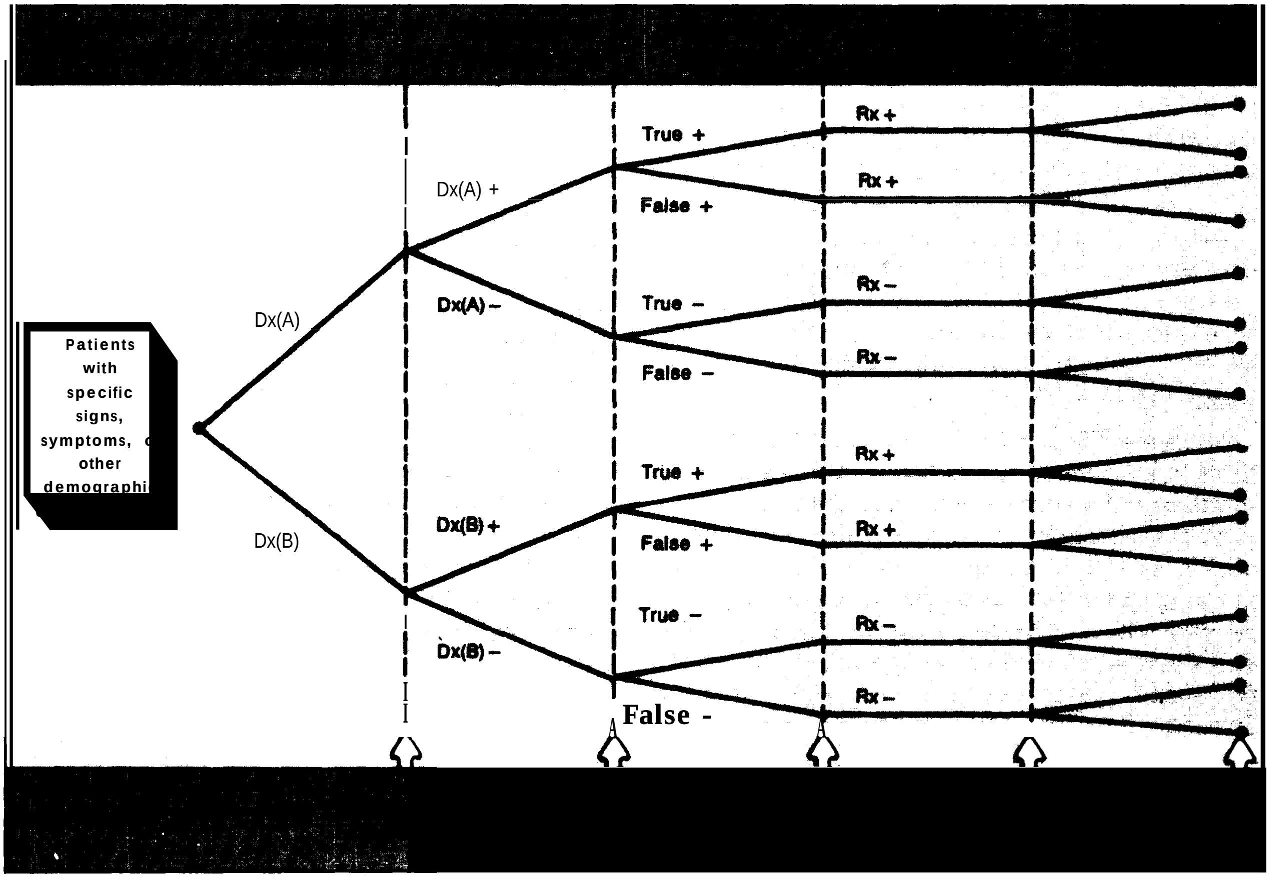
Although CEA eliminates the problem of placing a monetary value on benefits, its scope is limited. While the scope of CBA is the whole society, CEA'S is limited to the comparison of strategies with similar impacts. Since diagnostic procedures may have widely varying effects—some procedures may affect mortality while others may affect only the quality of life—CEA can only be used to compare a narrow set of procedures with similar purposes.

The application of CBA and CEA to diagnostic procedures can be described with reference to figure 1. A set of patients with specific presenting signs and symptoms faces two or more alternative diagnostic pathways, each representing a specific combination of diagnostic tests. These alternative pathways may represent different diagnostic tests or even different testing sequences. For example, pathway A might represent the administration of a radionuclide (RN) brain scan followed by a CT head scan if the RN scan is positive or equivocal, while pathway B might represent a CT scan only. Each of these two diagnostic pathways carries with it certain resource costs and has specific diagnostic results. Four possible diagnostic results are shown for each pathway: true positive, true negative, false positive, and false negative. Each of these outcomes implies a course of therapy (with negative findings implying no therapy), each involving its own resource costs. Finally, the therapies result in health outcomes measured by relevant indicators. In CEA, a single indicator or an index of indicators is chosen, and the impact of the pathway on this indicator is compared to the total resource costs (both therapeutic and diagnostic) associated with the pathway. The diagnostic pathway with the lowest ratio of cost to effectiveness is preferred. In CBA, all relevant outcomes, both good and bad, would be measured and their value assessed.

Notice that the purpose of economic evaluation is to decide under what conditions, if any, a diagnostic procedure should be used. Typically, a procedure will be of undisputed and obvious value for some groups of patients. The important question for resource allocation is not whether the diagnostic procedure or the equipment producing it is justified or whether the procedure raises or lowers health care costs, but how the procedures should be used in the practice of medicine. Only by knowing the costs and effects of treating each group of patients with the procedure is it possible to know whether there is too much or too little capacity to perform the procedure in any community.

As seemingly obvious as this point is, it has not been recognized by the authors of many studies purporting to be analyses of the cost effectiveness of CT scanning. Too many of these studies, whose titles include the term "cost effectiveness, " are simply historical descriptions of the aggregate impact of CT scanning on health

Figure 1 .—A Model for Economic Evaluation of Diagnostic Procedures



care costs in a hospital or community, These studies are plagued with measurement problems, but even without those problems, the studies would offer no guidance on whether the existing allocation of resources could be improved by increasing, decreasing, or rearranging CT scanning capacity in the United States.[1]

[1] Similarly, estimating the impact of a new procedure on medicare or public program expenditures, while useful in Federal budgeting, is not CEA.

PROBLEMS IN APPLYING THE IDEAL MODEL

The ideal model of economic evaluation is straightforward enough, but in attempts to apply it to diagnostic procedures, serious problems arise. Some of the problems are common to all economic evaluations. For example, the question of how one should compare costs and effects accruing at different times has not yet been fully resolved.[2] Several of the problems, however, arise in or are exacerbated by the attempt to apply the model to diagnostic procedures. Problems in the following areas merit a closer look:

- identifying homogeneous patient groups for analysis,
- specifying appropriate diagnostic pathways,
- measuring diagnostic accuracy,

[2] The main report of OTA's study, *The Implications of Cost-Effectiveness Analysis of Medical Technology* (36), contains an excellent summary of the general limitations of these methods.

- measuring diagnostic and therapeutic costs, and
- specifying outcomes of the diagnostic/ therapeutic process.

Each of these areas is discussed below.

Identifying Homogeneous Patient Groups

Application of the ideal model of economic evaluation requires dividing the universe of patients into reasonably homogeneous groups based on their presenting conditions and personal characteristics. The patients in each group, with a common set of signs and symptoms and perhaps other important characteristics, such as age or sex, are treated uniformly with respect to the diagnostic pathways applied.

The outcome of a CEA can be extremely sensitive to the criteria (signs and symptoms) used to identify a patient group. These criteria can be so general that they lump together patients with very different problems, or they can be so detailed that they essentially create a unique group for each individual patient. If, for example, an analysis of CT head scanning is based on a universe of patients with all types of neurological complaints, the CEA would average together the costs and outcomes associated with very different kinds of patients. Patients with recent strokes would be analyzed together with patients complaining of persistent headaches. At this extreme, the usefulness of economic analysis in discriminating between the appropriate and inappropriate uses of CT scanning is questionable. Conversely, if the criteria are so detailed that few patients fall into each group, the analysis would need to be repeated for each of the many groups of patients and would be prohibitively expensive. Moreover, such detailed criteria are impractical for use in diagnostic decisionmaking because they are likely to include subjective signs that are difficult to incorporate into a diagnostic protocol.

The problem of patient grouping is frequently noted in connection with clinical trials (38). As the number of groups of patients increases, the sample size required to show statistically significant effects also increases, possibly exhausting the supply of patients available for entry into a clinical trial. At the same time, aggregating may obscure significant benefits available to particular subgroups. But the problem is even more acute in economic evaluation, which must estimate costs associated with diagnosing and treating patients. Cost data are rarely available on a disaggregated basis, and allocation of aggregate costs to individual patient groups involves a loss of accuracy in cost measurement that can be quite serious.

Specifying Appropriate Diagnostic Pathways

The outcome of economic evaluation varies with the number of diagnostic pathways studied. Omission of significant alternatives can seriously compromise the results. If a new diagnostic test is developed for a previously undiagnosable disease, then the pathways in contention are easy to specify: the new test versus no test. But when a new diagnostic procedure adds information to that available from an existing arsenal of procedures, then each diagnostic pathway comprises a procedural sequence in which the performance of later procedures is conditioned on the achievement of certain results from earlier procedures. Moreover, two sequences that differ only in their rules for continuing the testing process must be considered separate diagnostic pathways, since each sequence will have yields and costs that are different from those of the other sequence. Hence, the number of pathways to be considered may be quite large, and the best pathways may inadvertently be excluded from analysis.

The importance of comparing alternative testing sequences places economic evaluation squarely at odds with principles for evaluating the accuracy of diagnostic procedures. Some of the best clinical studies of diagnostic procedures have measured the diagnostic accuracy of a given procedure independent of the outcome of the tests that precede or follow it. Indeed, a cardinal principle in measuring diagnostic accuracy of interpretive tests is that the reader or analyst should not be aware of the outcomes of previous tests (1). Yet, if knowledge of such outcomes would improve the accuracy or timeliness of diagnosis in a real clinical setting, and hence the potential outcomes of therapy, then that effect should be considered in the economic evaluation. Conversely, if knowledge of previous results tends to bias the findings in a particular direction, and hence leads to more misdiagnosis and inappropriate and costly treatment, that should also be considered in the economic evaluation. Unfortunately, the best efficacy studies specifically eschew the measurement of diagnostic accuracy in such biased but realistic settings. It is not surprising, then, that estimates of the relative frequency of outcomes of different diagnostic pathways are often lacking.

Any aspect of diagnosis or treatment that changes the parameters of the diagnostic pathway—either diagnostic accuracy, therapeutic effectiveness, or resource costs—requires definition of a new diagostic pathway. Moreover, a particular diagnostic pathway assumes a particular mix of inpatient and outpatient treatment. If two treatment protocols are identical except for the setting of care, then the protocols must be considered as separate pathways, since their costs may differ widely.

Technological change, which may improve the accuracy of a diagnostic test or the effectiveness with which the diagnosed disease can be treated, also requires the specification of new pathways. One accepted way of dealing with uncertainty about or changes in such parameters without constructing additional pathways is use of "sensitivity analysis." Sensitivity analysis systematically assesses the effect of parameter changes on the solution to the economic analysis. The question is posed as follows: What percentage change in the diagnostic accuracy of test X would be needed to induce a change in the analytic findings? The approach is powerful when only one or two parameters are subject to change or uncertainty, but it breaks down under conditions of general uncertainty about the appropriate value of many parameters. Unfortunately, most economic evaluations of diagnostic procedures face such conditions,

It should now be clear that the need to specify and compare a large number of alternative pathways to one another taxes both available data and analytical resources.

Specifying Diagnostic Accuracy

The model pictured in figure 1 is constructed as if each alternative diagnostic pathway yields only two diagnostic findings: positive and negative. Often, a positive finding is associated with several diseases or different stages of a disease. Hence, estimates of the total sensitivity (i.e., false-positive rates) and specificity (i.e., true negative rates)[3] of a diagnostic pathway are generally inadequate for economic evaluation, Each type of positive finding must be linked to the particular therapeutic pathway it evokes, so that the cost of that pathway can be estimated. Thus, for any patient group with specific presenting signs and symptoms, accurate economic evaluation requires data not only on the total sensitivity of a diagnostic pathway, but also on the rates of detection of the full spectrum of disease states that the diagnostic pathway might identify. Such detailed estimates are seldom available.

Measuring Diagnostic and Therapeutic Costs

Economic evaluation requires measurement of the diagnostic and therapeutic costs incurred when patients embark on a particular pathway. A CBA should measure the cost of all present and future health care stemming from the health problem that precipitated entry into the pathway in the first place. The cost of future health care made necessary by a false-negative finding, for example, should be included. In CEA, the criterion for inclusion of health care costs depends on the chosen indicator of effectiveness. The use of disability days as the effectiveness indicator would obviate the need for measurement of health care costs associated with treament of disability itself. Similarly, a cost-effectiveness study using the 5-year survival rate as the outcome measure of interest should count all costs up to the day of outcome

[3]The sensitivity of a diagnostic test is the proportion of all persons with disease whose test results are positive (true-positive rate). Specificity is the proportion of all persons without disease whose test results are negative (true-negative rate).

measurement. The cost of a false negative would be relevant only if it induced the delivery of additional medical care prior to the point at which effectiveness is measured. Thus, with CEA, there is a natural stopping point to cost measurement that is dictated by the time horizon implicit in the effectiveness measure.

Most of the cost-effectiveness studies of CT scanning have treated the measurement of diagnostic and therapeutic costs cavalierly, ignoring the difficult conceptual and measurement problems and taking ad hoc approaches without acknowledging their limitations. The authors of these studies either do not appreciate the difficulties inherent in cost measurement, or they recognize and are overwhelmed by the problems, and therefore ignore them. Nevertheless, the problems are great and may defy solution.

Cost is a measure of value—in this case, the value of productive resources (labor, equipment, supplies, etc.) that must be forgone to other uses when a particular diagnostic/ therapeutic pathway is chosen for the patient group under study. The appropriate economic concept is that of incremental or avoidable costs, those incurred as a direct result of committing a given increment of patients to a diagnostic therapeutic pathway or that can be avoided if the same patients do not take the pathway. Avoidable costs are treated as "variable, " while unavoidable costs are assumed to be "fixed ."

The definition of what is avoidable or variable depends on the time perspective of the decision and the size of the increment. Generally, the longer the time perspective and the larger the increment, the more costs are avoidable. Suppose, for example, that the decision is whether to perform CT scanning on patients with suspected stroke in a hospital with a scanner currently used at .50-percent capacity for other types of patients. In the very short run, the only truly avoidable costs are the materials, supplies, and extra wear and tear on equipment caused by serving the stroke patients. Most labor costs may be invariant with serving the new patients, because technicians must be paid for full workshifts whether they are busy or not. Consequently, the appropriate measure of cost would exclude these fixed operating costs. Also, because the equipment exists to serve other kinds of patients, the cost of capital required to provide the capacity should not be included in the measurement of incremental costs of serving the stroke patients. The short-run incremental cost of performing CT scans on stroke patients may thus be minimal. In the long run, however, capacity can be adjusted—perhaps through sharing of services—and staffing can be reduced. A portion of the costs of labor and equipment replacement must now be allocated to the new patients. Even in the long run, however, the incremental costs of a procedure should not include overhead for hospital administrative functions that do not vary with the capacity to perform the procedure.

Just as the time perspective influences the appropriate definition of incremental costs, so does the size of the increment. The provision of service to one additional patient may involve little extra cost, but even in the short run, the provision of services to a large number of new patients could involve the initiation of a second workshift or the addition of new capacity. In the extreme, one could imagine building new facilities to provide CT services to a large new patient group. Thus, regardless of the time perspective, the larger the size of the patient group, the more additional costs are unavoidable.

What is the appropriate time perspective for economic evaluations of diagnostic procedures? Such evaluations are intended to guide the allocation of resources, including capital investments. Thus, long-run incremental costs are the most appropriate measure for CBAs and CEAs. These long-run costs include all that arise, both at present and in the future, from the performance of the procedure under the assumption that capacity will adjust to the new demand. Therefore, it is reasonable to assign to a diagnostic/therapeutic pathway the costs of providing the additional capacity required to serve the patient group under study.[4] It is also reasonable to

[4]The additional capacity required to serve a particular patient group may involve the long-run provision of some excess capacity. Two conditions are particularly likely to require excess capacity: 1) when the patient group receives service on an emergency basis and procedures cannot be scheduled, and 2) when geographical access considerations mandate decentralized capacity. If all procedures could be performed on a scheduled basis at a single location, excess capacity would be unnecessary. The cost of providing excess capacity for these reasons is rightfully allocated to the patients for whose benefit the excess capacity is maintained.

assume that the service will be provided using the most efficient technology currently available to produce the expected diagnostic and therapeutic results. Therefore, the appropriate measure of capacity cost is not the original cost of the equipment and plant, but the current cost of replacing it.

Depending on the rates of technological change and general inflation, replacement cost may be quite different from the original capital cost of the equipment in any institution. But whereas the original cost of existing equipment is readily available from accounting records, estimation of current costs of replacing capacity is fraught with difficulty. Product improvements in CT scanning, for example, have increased equipment costs and improved the flexibility of CT scanning and the quality of resulting images. If these quality improvements are unnecessary to produce the level of diagnostic accuracy specified for the pathway, the measured costs of CT scanning should not be based on these new models. Whole-body scanners, for example, are increasingly used in studies of the head. Since the purchase price and operating costs of head scanners are less than those of body scanners, it would be incorrect to allocate to head scanning patients a portion of the extra costs associated with a body scanner. But how will one estimate the cost of replacing head scanners when they are no longer manufactured? The measurement of original capital cost, while inappropriate, is at least precise.

Whichever concept of capacity cost is used—original capital cost or current replacement cost—it must be allocated between the patient group under study and all other patient groups. A common rule of thumb is to allocate these costs in proportion to the share of total volume accounted for by the patient group under study. Underlying this rule is the implicit assumption that the costs of any excess capacity should be borne equally by each patient group using the service. In fact, this assumption may bias the analysis against certain patient groups. Headache patients, for example, may be able to wait weeks for a CT scan without negative effects on outcome, but may not have to do so because excess CT scanning capacity has been made available to serve trauma patients on an emergency basis. CT scanning costs allocated to the headache patients should rightly be calculated as if the equipment were used to full capacity, while the trauma patient group should bear the entire cost of the excess capacity. Such differential cost allocation has not been attempted in the CT scanning papers reviewed by this author.

Several economic studies of CT scanning have used hospital procedure charges to estimate the cost associated with the use of CT scanning. This approach is unacceptable, because procedure charges bear no relation to the incremental costs of treating particular patient groups. Even if each charge were set to equate the revenues from a procedure with its associated costs, which is seldom the case, the unit charge so constructed would be unlikely to reflect optimal utilization of capacity or appropriate allocation of indirect costs and overhead. It should be noted, however, that in most American hospitals charges for specific procedures are often completely unrelated to their costs. Profits from one procedure typically subsidize losses from another. Indeed, the hallmark of a good hospital administrator is that charges have been manipulated to maximize revenues. Consequently, the use of procedure charges as a proxy for incremental cost seriously compromises an analysis. The extensive reliance on procedure charges in economic studies of CT scanning is curious in light of the relatively detailed information available on the operating costs of CT scanning units (13,14). Although the obstacles are formidable, improved estimates of the cost of some procedures are within reach.

Another common practice in economic studies is to use physicians' fees as estimates of the value of physicians' inputs into the diagnostic and therapeutic processes. Although such fees represent actual payments, they are not accurate reflections of the value of physician inputs. Third-party payer policies have created anomalies in fee structures, so that some diagnostic procedures offer higher returns on the physician's investment of time and skill than others. In particular, fees for new procedures are often set higher than those for established procedures. A better approach to valuing physicians' services would be to use carefully constructed relative value scales based on the time and skill requirements of individual procedures. Construction of good relative value scales is expensive, however, and is unlikely to be undertaken as part of the evaluation of medical procedures. Some recent tentative evidence suggests that the California Relative Value Scale may be reasonably well correlated with the level of difficulty of surgical procedures i(19), but more investigation of this question is needed before it would be possible to recommend reliance on such a system.

To summarize, the obstacles to accurate measurement of the resource costs associated with a diagnostic/therapeutic pathway are great, but substantial improvement in cost estimates would be possible if researchers would attempt to approximate long-run incremental cost. At present, most cost analyses are grossly inaccurate, so much so, in fact, that wrong inferences have been drawn about the usefulness of CT scanning.

Specifying Outcomes of the Diagnostic/Therapeutic Process

CBA requires the specification of all significant kinds of outcomes of each diagnostic pathway. CEA assumes that a single measure or index can capture the essential nature of the outcomes. The former type of analysis challenges our present capacity to objectively quantify all types of effects, both good and bad, while the latter runs the risk of oversimplifying the decisionmaking problem.

The problem of specifying and measuring outcomes is common to all evaluation and is therefore beyond the scope of this case study. One type of outcome, however, is unique to economic evaluation of diagnostic procedures: the benefits derived from negative findings. Negative findings are certainly valued by patients, for such findings can have dramatic impacts on their peace of mind. The reassurance value of negative findings is generally ignored in CEA, because satisfactory methods for estimating changes both in patient satisfaction and in the value that patients place on those changes are lacking at present **(42).** Consequently, CEA is likely to be biased against diagnostic/therapeutic pathways offering high specificity (i. e., high true-negative rates) relative to those pathways with high sensitivity (i. e., high true-positive rates).

ECONOMIC EVALUATIONS OF CT SCANNING

Only two studies of CT scanning with which the author is familiar are good-faith efforts to implement the ideal model of economic evaluation in a comprehensive way. One such study, by Knaus and Wagner **(24),** is successful; a second study, by Baker and Way **(4),** represents a failure to understand and carry out the principles of economic evaluation.

Knaus and Wagner (24) analyzed the effectiveness and costs of two alternative diagnostic pathways for patients presenting with sudden severe headaches but no focal signs; such patients are generally viewed with skepticism as candidates for CT scanning. The analysts in this study compared the outcomes of two diagnostic pathways: 1) performing a CT scan on all such patients referred; and 2) performing a CT scan only on patients presenting additional neurological signs (i. e., depriving the patient of **a** CT scan unless and until his or her condition deteriorates). Only one possible positive finding was considered: a ruptured intracranial aneurysm resulting in subarachnoid hemorrhage. Because early diagnosis of this disease significantly improves the prognosis of surgical intervention, the authors concluded that the cost of each life saved by early detection is about $511,000, or $23,000 per life-year saved.

Knaus and Wagner observed that the analysis depended on the attainment of a diagnostic yield at least as high as that obtained at a large teaching hospital: about one aneurysm per 125 headache patients. The authors also demonstrated the high degree of sensitivity of cost-effectiveness ratios to small changes in this assumption.[5] It is also possible that finer criteria for offering CT scans to patients with severe headaches could lower the ratio of cost to lives saved by increasing diagnostic yield. For example, since aneurysms peak during distinct age intervals, age-based criteria might improve the estimates substantially.

Knaus and Wagner also observed that the study did not include the cost of errors, i.e., false positives and false negatives. In particular, if false positives lead to additional tests or unnecessary surgery with their attendant morbidity, mortality, and cost, the value of CT scanning as a primary diagnostic tool for severe headaches might be further reduced.

The authors of this study estimated the cost of CT scanning, including technical and professional components, at $255, basing their estimate on a reasonably good study of the average cost of a dedicated head scanner at capacity (17). They also assumed that CT scans administered to the patient group would be performed on an outpatient basis. Their cost calculation did not include the cost of therapies associated with each pathway; however, these costs may not greatly differ among the alternatives.

Incomplete as the analysis is, the Knaus and Wagner study demonstrates the potential power of economic evaluation in offering quantitative evidence about a controversial use of CT scanning. Whether restoring a life is worth $511,000 is a question for society. Should it be answered in the positive, the conventional wisdom that CT scanning resources should not be used on headache patients would need revision. More research is needed on the present signs, symptoms, and other factors that might improve the cost-effectiveness ratio for headache patients.

It is instructive to ask why Knaus' study met so many criteria for good economic evaluation. A critical determinant appears to be the availability of empirical estimates of the outcome of surgery, medical therapy, and no intervention in patients in various symptomatic stages of cerebral aneurysms. Without such probability estimates, the study would have foundered. The availability of data from clinical trials made possible the decision analytic approach for an admittedly narrow set of diagnostic findings for patients with headaches.

The study by Baker and Way (4) of CT scanning in the abdomen is a manifest demonstration of what can go wrong when clinicians attempt to apply the principles of economic evaluation. The authors randomly selected the case histories of approximately 200 hospitalized patients who had received body scans in 1976 or 1977. Each patient was classified according to the organ system studied (e. g., biliary, liver, etc.). Baker and Way then constructed an arbitrary scale of effectiveness, where a value of 1 was assigned to a patient for whom the CT scan had a lifesaving effect, a value of 18 was assigned to a patient if the CT scan actually precipitated a death, and a value of 10 indicated no net value. The costs of CT scans and other related diagnostic tests were presumably estimated from the procedure charges, although the authors did not specify their methods. A ratio of cost to effectiveness was constructed for each organ system, with the effectiveness scale value as the denominator. The authors concluded that "the differences between the categories [organ systems] are insignificant, and the average result suggests that, in general, the value of the scans to medical care in relation to the cost of scans was low, "

Apart from the obvious question of the reliability of subjective assessments of effectiveness and the cost measurement techniques, two criticisms of Baker and Way's study are relevant here. First, it is utterly meaningless to compare the cost-effectiveness ratio of CT scanning across patient groups. The appropriate comparison is between CT scanning and other diagnos-

[5]In a study of 161 headache patients referred to EEG evaluation, Larson, et al. (28) found none with subarachnoid hemorrhages. However, all patients in this sample were selected for study because they had been referred for an EEG (some had also had scans), and the specific nature and history of the headache were not specified. Whereas Knaus focused on patients with sudden onset, the Larson data were not so specific. The observed difference in diagnostic yield between the two studies illustrates the difficulty of drawing generalized conclusions from single-institution studies using different referral networks and criteria for inclusion of patients in the study.

tic procedures for each particular patient group. The relevant question is whether the cost-effectiveness ratio can be improved if, for example, liver patients are given another diagnostic procedure, perhaps a sonogram, instead of a CT scan. Only by comparing patients scanned and similar patients not scanned can this be answered.[6]

The second criticism relates to Baker and Way's use of the effectiveness scale as if it represents cardinal values. Since the numerator of the ratio (cost) is a constant cardinal number, the relative advantage of alternative diagnostic tests would change with the choice of effectiveness scale. Thus, the authors' conclusion that "for many abdominal conditions ultrasound scans are . . . substantially more cost-effective than CAT body scans . . ." is patently unsupported by the data presented in the study.

Studies of the Impact of CT Scanning on Diagnostic Costs

No other studies known to this author have compared costs with effectiveness. The most common departure from the ideal is to evaluate the impact of CT scanning on diagnostic cost, ignoring its impact on resultant therapies and outcomes. Under some conditions, this more narrow approach to evaluating diagnostic alternatives is sufficient. If, for example, a diagnostic pathway has the lowest diagnostic cost and is at least as safe, accurate, and timely as all other relevant pathways, then it is optimal. The problem arises when the diagnostic cost of a pathway is higher than that of alternative pathways but is accompanied by greater diagnostic accuracy, safety, or speed. Then one must assess the tradeoff between cost and quality of diagnosis in terms of each pathway's impact on therapy and outcome. Thus, analysis of the impact of CT scanning on the cost of diagnosis is a logical starting point but is generally an insufficient approach to economic evaluation.

The fundamental weakness of the studies remaining to be discussed, therefore, is not their failure to consider therapies and outcomes. Rather, it is their choice of diagnostic pathways. Each one of these studies compares actual patterns of diagnosis with and without CT scanning. Most are pre-CT/post-CT comparisons of diagnostic costs in an institution or country. Given the system of medical practice in force today, however, there is no uniformity from physician to physician in the use of diagnostic procedures on similar patients. Since one physician may order a battery of tests simultaneously, while another may move cautiously from one to another, each diagnostic pathway comprises many approaches to diagnosis. Thus, to show that the introduction of CT scanning has historically raised or reduced diagnostic costs is to show that and nothing more. That finding holds no implications for resource allocation, because the pathways are too amorphous to determine how CT scanning should fit into the diagnostic process.

Homogeneous patient groups, however, are likely to undergo diagnostic strategies that are reasonably uniform. Therefore, empirical studies of the impact of CT scanning on diagnostic cost are more likely to be useful as resource allocation tools when these studies are concentrated on a narrow set of presenting signs and symptoms.

Three studies of specific patient groups with relatively unambiguous and homogeneous signs and symptoms were reported by Larson and colleagues at the University of Washington. They analyzed the impact of CT scanning on the utilization and cost of diagnostic services for patients with presenting conditions suggestive of brain tumors **(26),** cerebrovascular disease (27), and hydrocephalus (30). Admission forms were abstracted for all inpatients admitted to the university-affiliated hospital with signs and symptoms suggesting one of the three diseases during the year prior to and 2 years after the introduction of a CT head scanner. Patterns of service

[6] The authors did attempt to address this question by constructing cost-effectiveness ratios for sonograms performed on a subset of the CT scan patients, but nowhere did they say how the effectiveness value for a sonogram was obtained. They asserted that CT scans and sonograms are "of about equal clinical value in any given situation," presumably basing their assertion on an analysis of the sensitivity and specificity of the two tests; however, it is not clear whether, in constructing the cost-effectiveness estimate, they assumed that a patient would have received the same subjective effectiveness score for a sonogram as for a CT scan.

delivery and medical care in the pre-CT and post-CT patient groups were compared, including the utilization of and charges for neurodiagnostic procedures; the length of hospital stay; the time required to reach final diagnosis; the level of detail of the diagnosis; and the type of therapy employed, CT scanning had a major impact on the configuration of diagnostic studies used for each of the three types of patients, but the relative benefits resulting from these changes varied among the three.

In the study of patients with suspected brain tumors (26), CT scanning significantly reduced the use of RN brain scanning (from 85 to 38 percent of patients), angiography (from 65 to 50 percent of patients), and pneumoencephalography (PEG) (from 15 to 4 percent of patients). The length of hospitalization, speed of diagnostic workup, and timing and type of therapy for these patients, though, did not change significantly. The overall detectability of brain tumors increased markedly after CT scanning became available. Total per-patient hospital charges for neurodiagnostic procedures did not change significantly. The authors therefore concluded that CT scanning as it was integrated into the neurodiagnostic process at the study hospital was cost effective, because it permitted reductions in the use of invasive and somewhat risky procedures but did not raise hospital charges or otherwise affect prognosis,

In the case of patients with suspected cerebrovascular disease (27), the introduction of CT scanning significantly reduced the number of lumbar punctures and RN brain scans, but the total per-capita hospital charge for neurodiagnostic procedures increased about 33 percent. The length of hospitalization and speed of diagnostic workup did not change, and although the level of detail of the discharge diagnosis was greatly increased, such detail was unnecessary to plan therapy. In the judgment of the authors, CT scan results were not essential to establishing a diagnosis in these patients but played a confirming role. In patients with suspected cerebrovascular disease, therefore, CT scanning was found to be of questionable value.

The introduction of CT scanning in the diagnostic workup of children with suspected hydrocephalus (30) led to major reductions in RN brain scans and PEGs. CT scanning also reduced the total charges for neurodiagnostic procedures. Speed of diagnosis, length of hospitalization, and kind of therapy did not change. Thus, CT scanning was found to be particularly appropriate for such patients.

All three Larson studies depended on the use of procedure charges as a proxy for the economic costs involved in performing the neurodiagnostic procedures. The resulting distortion of estimated cost impacts is instructive. In the study of suspected hydrocephalus (30), total estimated diagnostic charges dropped precipitously with the advent of CT scanning, largely because of the high charge for a PEG examination ($492 at the study hospital). The high charge at least partly reflects that procedure's relative rarity and the existence of excess capacity. The long-run incremental cost of a PEG examination is probably much lower. Were such examinations not painful and risky, and therefore to be avoided wherever possible, a substantial change in the estimated cost of this procedure could have reversed the findings regarding the benefit of CT scanning in patients with suspected hydrocephalus. In fact, a PEG procedure charge of $200 would have resulted in no difference between pre-CT and post-CT total per-capita charge for neurodiagnostic procedures, and the analysis would have rested on the implications of substituting CT for PEG examinations for patient morbidity and risk.

The investigation did not question the appropriateness of inpatient versus outpatient workups. Some neurodiagnostic studies can probably be performed on an outpatient basis. By accepting the existing settings of care as the basis for comparison, the studies may have overlooked particularly efficient alternatives.

The three Larson studies do show, however, that with good hospital data systems and effort and persistence on the part of the investigators, it is possible to identify patients with reasonably homogeneous presenting signs and symptoms. The ability to obtain medical records categorized by admission problem rather than discharge diagnosis is critical for estimating the outcomes of different diagnostic pathways, and although the Larson studies do not specify pathways with sufficient clarity, their patient identification methodology would support such analyses.

A more recent study by the same authors investigated the impact of outpatient CT scans on headache patients **(28).** Three cohorts of patients were selected for study: one cohort containing patients seen before installation of a CT scanner, a second cohort containing patients seen shortly after installation, and a third cohort containing patients seen 1 year after installation of the CT scanner, The patients in each of these cohorts were selected from a review of electroencephalogram (EEG) records, where headache was the reason for the EEG. Thus, the patient sample excluded those who may have had CT scans without EEGs. The cost of diagnostic tests was computed using procedure charges; the diagnostic testing charges per patient increased 16 percent after the introduction of CT scanning. The neuroradiologic diagnostic yield of patients with normal neurological workups was low, and, in the case of CT, was negligible. This finding led the authors to suggest that abnormal findings on neurological examination should be a screening criterion for performing CT scans and other neuroradiological procedures for patients with headaches.

The fact that diagnostic charges increased after the introduction of CT scanning says very little about the appropriate allocation of resources; the more powerful evidence presented by the authors is the apparent absence of real clinical benefit, even with respect to diagnostic capability, deriving from CT scanning—and, indeed, from most neurodiagnostic procedures. If radiological and other technology-bound procedures are to be performed on patients with no focal findings, then this study has not adequately demonstrated that CT scanning cannot lower the cost of diagnosis if it is appropriately substituted for other tests. A clear cost-reducing option, however, appears to ensue from stopping the diagnostic workup of the patient when the clinical examination reveals no abnormalities. In light of the importance of such a conclusion, it is unfortunate that the sample of patients in this study was chosen by excluding those who may have had CT scans without EEGs. More needs to be done to refine the study of diagnostic procedures for patients with headaches.

Ambrose and his colleagues (2) in Britain studied the impact of CT scanning on the diagnosis of head injuries, but they did not attempt to attach cost estimates to the observed changes in utilization of diagnostic procedures and exploratory surgery. The introduction of CT scanning at the study hospital dramatically reduced the use of arteriography, PEG, and exploratory craniotomy without changing the mortality rate; however, once CT examinations were available, they were ordered so frequently that net costs may have increased. Nevertheless, the realized effect is not the relevant question for resource allocation. CT scanning can undoubtedly reduce the cost of diagnosis for some patients by substantially reducing the high cost, morbidity, and mortality associated with the diagnostic procedures it replaces. The real question though, is how to achieve the best results. Like previous studies, the Ambrose study failed to explore how CT scanning might optimally be integrated into diagnostic and management protocols.

In a recent study of CT scanning in acute head trauma at a U.S. teaching hospital, Zimmerman, et al. (47) noted a progressive decrease in utilization of skull X-rays following the introduction of CT scanning, but they also observed that "a certain proportion of the present skull radiographic examinations are done because of the referring physician's adherence to traditional ways of evaluating trauma patients. " A critical question that economic analysis might address is exactly when, if at all, skull X-rays should be employed in the evaluation of patients with head trauma.

Bahr and Hodges (3) investigated the impact of CT scanning on the total cost of hospital care (measured by billed charges) for neurological and neurosurgical inpatients at a university hospital. The total average hospital bill for these patients decreased about 10 percent, after adjusting for inflation, but the decrease was not statistically significant. The study population was disaggregated into three diagnostic groups:

1) patients with extracerebral collections, 2) patients with proved intracranial tumors, and 3) patients with vascular disease. The total inflation-adjusted hospital bill for patients in the first two categories decreased by 23 and 35 percent respectively, while that of the third group increased by 30 percent.

It is difficult to interpret such findings because of the possibility that the patient mix changed over the period, especially if the availability of CT scanning enabled testing of some as outpatients. In addition, the study population is ambiguous, consisting of patients with all types of neurological complaints. The disaggregated cost comparisons are based on final diagnosis, not on the patients' presenting signs and symptoms. Consequently, the cost or savings by diagnosis are irrelevant to the use of CT scanning under specified presenting conditions. The difficulty of interpreting cost impacts based on procedure charges has already been noted.

In one of the earliest economic impact studies, Wortzman, Holgate, and Morgan (45) reviewed the records of over 200 inpatients who were given CT head scans at a Canadian hospital. In each case, the authors judged whether an angiogram or PEG had been prevented or prompted by the CT scan. The hospital costs (measured by charges) saved or induced by use of the CT scan were calculated on the assumption that the hospital stay for an angiogram is 1 day and that for a PEG examination, 3 days. Net savings resulting from the availability of CT scanning were estimated at $300 per patient. In a second part of the study, the authors reviewed all outpatient CT scans at the hospital and, with the help of a survey of referring physicians, estimated that 58 percent of the outpatients would have been hospitalized had the CT scan been unavailable. Assuming that these patients would have stayed the average length of stay in neurology (14 days), the authors estimated that CT scanning saved $1,490 per outpatient scan.

The vulnerability of the savings estimate to changes in assumptions is obvious and needs no further comment. Nor does the use of charges to reflect cost. The method for determining the degree of substitution of CT for other procedures is judgmental and therefore subject to investigator and respondent bias. Most important, however, the aggregated nature of the patient group under study mitigates the value of the findings. It is certain that savings, however measured, could be further increased by more detailed analysis of presenting signs and symptoms.

In a recent reappraisal of their early study, Wortzman and Holgate (45) revealed discrepancies between their estimates of potential savings and realized effects in subsequent years. Hospital stays and admissions did not decline as predicted in the study. Although the number of angiograms and PEGs did decline, the cost of these procedures, as measured by charges, rose, thus wiping out much of the estimated savings. The procedure charge increases were necessitated by decreases in utilization without concomitant capacity reduction. But the authors wrongly assumed that estimated cost savings should be altered to reflect these changes. The principle of long-run incremental cost requires the assumption that capacity will ultimately adjust to reduced demand.

A study by Thomson (41) at Frenchay Hospital in Great Britain traces changes in the use of particular procedures and services in the 2 years following the installation of a CT scanner. There, as in most other institutions, the number of arteriograms, RN brain scans, and PEGs declined after the introduction of CT scanning; the length of stay of neurosurgical inpatients declined as well, and admissions were avoided. The cost of operating a CT scanner at the study hospital was meticulously calculated using a modified concept of capacity replacement cost and assuming operation at full capacity. The economic cost of other neurodiagnostic procedures made unnecessary by CT scanning were not measured so carefully, but were assigned relatively low values in order to bias the study against CT scanning. Hospital stay savings were estimated at the average daily cost of a National Health Service hospital bed. CT generated net savings for the hospital, and, by inference, for the National Health Service, although the savings were minimal,

Since Thompson made no attempt to follow a specific patient group but merely reported on institutionwide changes in utilization of services, it is impossible to know the kinds of patients for whom CT scanning is cost effective. Other authors have documented such institutionwide changes **(26).** This kind of information, even when linked to good cost estimates, ignores the central problem for medical decisionmaking and health facilities planning: To what uses should CT scanning capability be applied?

Two studies have attempted to estimate the impact of CT scanning on the national cost of diagnosis in the United States. Willems, et al. (44) estimated net changes in total U.S. expenditures for diagnosis due to the introduction of CT scanning. The performance of a CT scan generated a technical charge, professional fee, and associated hospital room and board charges, all of which totaled an amount between **$295** million and **$428** million in **1976.** Savings resulting from reduction in PEGs, RN brain scans, and arteriograms were deducted from this total, leaving a net estimate of $181 million to **$390** million in increased expenditures due to CT scanning in 1976.

Like analysts in most of the other studies previously described, Willems used procedure charges to estimate the cost of most procedures. Although charges are an inadequate surrogate for resource costs, they do reflect real transfers from payers to providers of health care; in that sense, the total expenditure burden imposed by CT scanning is of interest. It is unknown, however, whether the expenditures were used to subsidize the provision of other services that hospitals provide at a loss or, perhaps, whether the expenditures were used to inflate physician or other professional incomes.

A study by researchers at Arthur D. Little, Inc. (17) represents the only effort to date to estimate the national impact of both head and body scanning on the cost of diagnosis. The national impact on the utilization of competing diagnostic procedures and exploratory surgery in **1977** and 1980 was estimated by a variety of sources, including consultations with experts in the field. The technical cost of providing each type of procedure was estimated assuming equipment at full utilization and current costs of replacement of equipment. (Except for exploratory surgery, charges were not used to estimate procedure costs.) To arrive at a unit cost for each of the various diagnostic procedures, the national average hospital room and board charge was applied to the additional days of hospitalization required by each type of procedure.

It was predicted in the A.D. Little study that the availability of CT head scanning would raise diagnostic costs by about $29 million in 1977 and $31 million in 1980. These low estimates of net impact contrast with the results of the Willems study but can be explained by different assumptions about the effect of CT scanning on exploratory surgery and skull X-rays.

The predicted impact of CT body scanning is subject to greater speculation since, at the time of the study, body scanning had only begun to find its way into the diagnostic process. The authors predicted that in 1980, as a result of the use of CT scanning, the estimated cost of diagnosing abdominal and mediastinal disorders will have increased by $152 million. This estimate is based on the assumption that the availability of CT body scanning will reduce the number of exploratory surgeries by 50 percent and that no other diagnostic procedures will be affected by CT scanning.

Although the ultimate significance of these estimates for decisionmaking is most certainly low, the A. D. Little study represents the best effort to date at estimating the resources costs associated with performing diagnostic procedures. Capacity costs were based on current equipment replacement prices and full capacity. However, indirect costs (administrative expenses in departments outside of the CT scanning unit) were arbitrarily assigned a value of **50** percent of direct costs, a level that probably bears no relation to the actual incremental costs associated with the existence of the CT scanning capacity. The technical cost of surgery and routine costs of hospital care were based on charges rather than costs. With the high cost of hospital construction today, hospital room and board charges reflecting original capital costs probably understate replacement costs, In spite of these shortcomings, the method for estimating procedure costs is a model for economic evaluation of CT scanning.

Studies of the Cost of Case Finding

A commonly advocated approach to economic evaluation is the calculation of the cost of case finding, which is variously defined as "the cost per positive finding," "the cost per correct finding," or "the cost per true positive" **(6).** The cost of case finding is a concept borrowed from the economic evaluation of screening procedures. It is particularly useful in determining which of two or more mutually exclusive screening procedures is more cost effective in detecting a particular disease in an asymptomatic population. A procedure (or sequence of procedures) that costs the least per true positive finding is preferred to all others.

Unfortunately, the concept does not travel well. When applied to analysis of CT scanning, which is used on symptomatic patients in conjunction with other tests, the cost of case finding is meaningless. The results of studies using the concept illustrate its limitations.

Carrera, et al. (9) calculated the cost per abnormal CT scan for three types of cases: 1) headaches without neurological findings, 2) headaches with neurological findings, and 3) suspected temporal lobe epilepsy. Because of differences in the diagnostic yield of CT scanning among these three types of cases, the cost per abnormal CT scan examination was $4,000; $1,300; and $2,000 respectively.[7] In a separate study, Knaus and Davis (23) calculated the case-finding cost of CT scanning for **25** leading indications for CT head scanning. The case-finding cost at the study hospital ranged from $411 for patients in coma to **$3,500** for patients with headache. Larson, et al. **(28)** estimated that the cost of case finding for headache patients without abnormal neurological findings was $11,901. The authors of all three papers questioned the cost effectiveness of CT scanning in patients with headaches without neurological findings. Any conclusion about cost effectiveness is premature, however, for the cost of case finding can only be compared to the benefits of finding abnormalities in the patient group.

Evens and Jest (12) have used the concept of case-finding cost to compare CT head scanning and RN brain scanning on patients with neurological complaints. Using estimates of sensitivity and specificity of CT and RN scanning, the authors calculated the cost per correct finding: CT scanning cost $141 per correct finding; RN scanning cost $73 per correct finding. Although, on the surface, this finding would imply that RN scanning is the procedure of choice, Evens and Jest observed that CT is a more sensitive test. Hence, in a large number of cases, the combination of the two tests would be ordered, with a joint cost per correct finding of $214. If an initial negative RN scan generates a confirmatory CT examination in at least **60** percent of neurological cases, then an initial CT scan costs less per correct finding than an initial RN examination.

Notice that Evens and Jest used a variant of case-finding cost. Whereas Carrera (9) and Knaus and Davis **(23)** calculated the cost per abnormal or positive finding, Evens and Jest calculated the cost per correct finding. A third approach, the cost per true positive finding, has also been used.[8] The relative merit of these alternative measures of case-finding cost depends on the errors in diagnosis and implications for therapy of each alternative. In fact, the most appropriate measure can be selected properly only if the costs and benefits of pursuing diagnostic pathways to their ultimate outcomes are known.

This point can be illustrated algebraically. Let TP, FP, TN, and FN denote the proportion of true positives, false positives, true negatives, and false negatives expected from a given diagnostic pathway in a specified population of patients. Let C be the total cost of performing

[7] A CT procedure charge of $240 was used as a surrogate for cost.

[8] See, e.g., B. J. McNeil and S J. Adelstein, "Measures of Clinical Efficacy. The Value of Case Finding in Hypertensive Renovascular Disease," 1975 (32).

diagnostic procedures on these patients. The three case-finding cost options are:

$$\text{Cost per true positive} = \frac{C}{TP\ (100)}$$

$$\text{Cost per abnormal finding} = \frac{C}{(Tp + Fp)\ (100)}$$

$$\text{Cost per correct finding} = \frac{C}{(TP + TN)\ (100)}$$

Suppose that two diagnostic procedures, A and B, have the disease detection rates shown in figure 2 when performed on a patient group with a **0.50** disease prevalence rate. Assume also that both procedures cost the same to administer, $10 per patient. Figure 3 gives the case-finding costs of each procedure for each 100 patients **as** measured by the three case-finding options. In figure 3, diagnostic procedure B would be preferred if the option "cost per correct finding" were used, and diagnostic procedure A would be preferred under the options "cost per true positive" and "cost per abnormal finding. "

Suppose, however, that the implications of a false negative are major (e.g., a fatal but completely treatable disease goes undetected), while those of a false positive are minor (e. g., inexpensive additional tests are required). Clearly, diagnostic procedure A would be preferred, and use of the cost per correct finding would be unacceptable. Similarly, if the implications of a false positive are major (e.g., application of inappropriate, expensive, and risky therapy), while those of a false negative are also great, then the use of cost per correct finding is superior. Thus, to accurately determine which measure of case-finding cost is preferred, it is necessary to know something about the subsequent benefits and costs resulting from a particular diagnostic procedure. The more that is known, the more accurate can be the weights put on the different kinds of errors. Thus, case-finding costs do not bypass the need for information concerning the full implications of embarking on a diagnostic pathway.

Figure 2.—Disease Detection Rates for Two Tests

Test results		
+	[illegible]	[illegible]
−	[illegible]	$TN_A = 0.10$ $TN_B = 0.45$

Figure 3.—Case-Finding Costs for 100 Patients

Diagnostic test	Cost per true positive (C/TP)	Cost per correct finding (C/TP + TN)	Cost per abnormal finding (C/TP + F?)
A	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible] = $40.00

Studies of CT Scanner Capacity and Location

In many countries, public or quasi-public health agencies are responsible for directing or influencing decisions on investment in CT scanning capacity. In the United States, areawide and State health planning agencies are charged with review and approval of hospitals' applications for major equipment acquisition. In Sweden and Great Britain, regional authorities must allocate funds for the purchase of major medical equipment.

It is not surprising, then, that some effort has gone into developing methodologies for determining the optimal number and sometimes location of CT scanners in a region. In the United States, most of the effort has been devoted to assessing "need" for CT capacity, without incorporating economic criteria into the analysis. Such "need assessment" methodologies[9] are not reviewed here, since they do not explicitly take account of costs. However, three studies known to this author have included the costs of alternative capacity/location choices. It is instructive to investigate how these approaches deal with the lack of information on the kinds of patients for whom CT scanning is a cost-effective procedure.

Jonsson and Markė (21) reported on a Swedish study of CT scanning in which the net cost of locating a CT scanner in a hospital was estimated as a function of the degree to which CT scans would substitute for angiographic and PEG studies. If a hospital could eliminate enough of these other procedures, then the introduction of the CT scanner would result in net savings to the hospital. The authors observed that in most Swedish hospitals with PEG and angiographic capability, so few examinations are carried out that not even a 100-percent reduction of both of these procedures would justify installation of a CT scanner on cost grounds alone. Other criteria, including effectiveness, would be needed to guide the decision. In larger regional hospitals, however, where at least **500** angiograms and **200** PEGs could be eliminated each year, the CT scanner would save money.

The cost analysis rightly assumed that all radiographic equipment is operated at capacity both before and after the introduction of CT; this avoids ascribing to CT scanning savings that would otherwise be obtainable from consolidating radiographic services in larger hospitals, In fact, the whole question of CT scanner location appears to be inextricably linked to the optimal distribution of neuroradiologic capacity as a whole, Costs could be reduced by regionalizing such capacity, but these savings would have to be compared to the added cost of transportation to regional facilities. For emergency patients, the cost savings would also have to be weighed against reduced access to care. Thus, the Swedish study, though excellent in its costing methodology, is still limited as a planning approach, since it analyzes the effect of introducing CT scanning to an already existing system in which the present allocation of radiological resources may very well be inappropriate.

Bartlett, et al. (7) reported on a comparison of alternative options for the location of CT scanning capacity in a particular region of England. The study assumed that the demand for CT scans would be 3.5 per thousand residents per year. Alternative configurations for meeting (and exceeding) that demand were then compared. The critical question was whether CT scanning capacity should be installed in all hospitals with neurosurgery, neurology, and accident centers. The not so startling conclusion was that more scanners would cost more money and the added cost of installing a CT scanner in every accident center (far exceeding the required scanner-to-population ratio) must be compared to the lifesaving potential of the scanner in head trauma. We are thus led full circle back to the basic question of the conditions for which CT scanning is economically justified.

An American study by Greenwald, et al. (18) is an application of a mathematical optimization technique to the question of scanner capacity and location. The authors formulated the problem thus: How does one choose the number and location of CT scanners such that the sum of CT

[9]For a review of some early needs assessment methodologies for CT scanning, see Institute of Medicine, *Computed Tomographic Scanning: A Policy Statement*, 1977 (20).