ABSTRACT: The influence of IT investments on organizational performance is revisited. Bounded rationality, organizational controls, and political forces may constrain optimal selection of inputs and appropriate substitution between inputs. For example, firms may not be able to attain an optimal level of IT by substituting IT for labor (for reasons such as pressure from the labor union). Besides estimating a link between IT investments and firm output, this paper presents a study of the link between IT investment levels and the efficiency of processes.

Nonparametric and parametric techniques were applied to financial data on hospitals collected over a period of eighteen years. We found that cost and technical and allocative efficiencies are statistically significant in the production framework. We also found that hospitals that were characterized by high technical efficiency also used a greater amount of IT capital than firms that exhibited low technical efficiency. A group of hospitals exhibiting high technical efficiency also exhibited low allocative efficiency, indicating that, while processes may have been efficient, resource allocation and budgeting between various categories of capital and labor have not been efficient. Our results also differ from previously published results because we find that IT labor had a negative contribution to productivity and that non-IT capital had a greater contribution to productivity than IT capital.

KEY WORDS AND PHRASES: allocative efficiency, information technology performance, process efficiency, technical efficiency.
NORMATIVE ANALYSIS OF THE VALUE OF IT HAS FOCUSED ON POST-HOC econometric analyses using parametric and nonparametric techniques (e.g., [1, 6, 19, 22]). The main purpose of studies in this area was to determine the direct or indirect contribution of IT in increasing the output (that is, productivity impacts of IT) of the firm. For an extensive review on the IT productivity paradox, readers are referred to [7]. This paper revisits the IT productivity issue but extends discussion on the issue in the following manner: First, the analysis is based on both nonparametric and parametric production approaches, compared with the parametric approach alone, as in prior studies on IT productivity. Second, in addition to productivity measures, the estimation of the error terms that specifically represent various inefficiencies in the production process is shown to be a valuable byproduct of the analysis. Efficiency, when measured through post-hoc analysis, tells us how well the final mix of inputs has affected production (technical efficiency) and also how well costs and productivity impacts of inputs were factored into decision-making during resource allocation (allocative efficiency). Third, we compare efficiency estimates obtained from both parametric and nonparametric techniques to infer the complexity of the changes to the underlying production technology over time. The use of multiple techniques also helps us examine the robustness of the empirical results. Finally, this study uses data covering a long period (18 years) and was collected from relatively homogeneous organizations (hospitals). The data were defined and monitored by government regulations.

Our results support the association between IT capital and increased productivity. However, these results also showed that IT labor was associated with decreased productivity. This contradicts results obtained by others (e.g., [15]) that IT labor made a large contribution to firm productivity. We found that cost and technical and allocative efficiencies are statistically significant variables in the production framework. We also found that firms that were characterized by high technical efficiency also used more IT capital. However, these firms may have overinvested in IT by not suitably selecting lower-priced IT. This was indicated by the high technical efficiency and low allocative efficiency values in several firms. It would seem that, while process reengineering has been effective in streamlining operations, resource allocation and budgeting between various categories has been suboptimal. Furthermore, a comparison of the results using parametric and nonparametric techniques suggested that technical progress in the industry might have changed production characteristics over time. This comparison also revealed that the period of observation (1976–94) may be divided into three periods of significant transformation in business processes. These periods correspond roughly to the often cited paradigm shifts in IT: the mainframe era in the 1970s and early 1980s, PC introduction in the mid-1980s, and distributed computing such as client-server architecture and the Internet in the 1990s. IT contribution in the post-PC era appeared to be much greater than in the earlier periods.

Theory and Background

IN THIS PAPER IT VALUE IS ASSESSED USING THE NOTION OF EFFICIENCIES—overall efficiency, technical efficiency, and allocative efficiency [20]. These efficiencies are
best understood using the Input-Control-Output-Mechanism (ICOM) model of produc-
tion (figure 1) used in a business-process modeling tool, IDEF [25]. ICOM defines
mechanism as the object, such as person or machine, that carries out the function.
Controls are defined as the conditions, rules, procedures, or circumstances that gov-
ern the execution of the function. The control aspect of the model captures process
control and design, which is typically an operational decision.

If the process as conducted by the mechanism or due to the inadequacy of controls
is inefficient, then a low value of technical efficiency will be observed. Technical
inefficiency results from a poor choice of input quantities and is a measure of the
wastefulness of the current choice of input quantities in producing the desired amount
of output. Streamlining operations leads to better technical efficiency. The concept
of various efficiencies in production is illustrated in figure 2, a diagrammatic represen-
tation of a generic production process using two inputs, \( X \) and \( Z \), and producing
one output, \( Y \). The \( X-Z \) quadrant is called the input space. The point \( R \) in the input
space represents the current production status (the amounts of \( X \) and \( Z \) chosen to
produce \( Y \)). The minimum amounts of \( X \) and \( Z \) that can together produce \( Y \) is repre-
sented by the point \( S \). The locus of all minimum combinations of \( X \) and \( Z \) that can
produce the output amount \( Y \) is shown as a curve \( Y \) on the input space. The graph
\( Y \) represents the best-practices frontier for this production technology. Technical effi-
ciency of the process is given by the ratio \( OS/OR \), which is the proportion by which
input quantities can be radially (and feasibly) reduced and yet produce the amount \( Y \).

Pioneering definitions of technical efficiency by Koopmans [17], Debreu [10], and
Farrell [13] were extrapolated to define cost efficiency, allocative efficiency, and
scale efficiencies [20].

Price plays an important role in cost and allocative efficiency. Draw a line \( PQ \)
whose slope is equal to the ratio of the prices of \( X \) and \( Z \). All \( X \) and \( Z \) combinations on
this line will add to the same total cost (hence, \( PQ \) is also called an iso-cost line). By
placing \( PQ \) tangential to the graph \( Y \), we can graphically determine the point \( E \) that
represents the feasible, minimum-cost combination of \( X \) and \( Z \) that will produce \( Y \).
Figure 2. Efficiency in Production

The point $T$ at the intersection of $OR$ and $PQ$ represents an infeasible combination with the same minimum cost as the feasible combination $E$. Then, the ratio $OT/OS$ measures the proportion by which the cost of a technically efficient input mix, given by $S$, is higher than the minimum feasible cost of production given by $T$ and $E$. This ratio is called the firm-specific allocative efficiency, $FAE$. Further, the slope of the graph $Y$ at point $S$ is the current ratio of the marginal products of $X$ and $Z$. The difference of this slope from the slope of $PQ$ is called input-specific allocative inefficiency, $IAE$, between inputs $X$ and $Z$. This is because, under equilibrium, the ratio of the marginal products of $X$ and $Z$ must equal their price ratio.

In case the amount of output can also be manipulated and was not chosen correctly, the production exhibits scale inefficiency. In this study, we assume that hospitals adopt cost-minimization behavior. Cost minimization behavior implies that the output level is not controlled. Hence, scale efficiency is not relevant to our study. The various inefficiencies described above (technical and allocative) combine and result in cost inefficiency.

The inclusion of technical and allocative inefficiencies present a very realistic picture of firm operations by explicitly modeling two factors:

1. No two firms can produce the same level of output using identical levels of input such as IT resources.
2. Firms do not allocate resources at the optimal level given by the first-order condition of cost minimization, which implies that the ratio of the marginal products of inputs must equal the ratio of their prices. This may be due to several practical reasons such as bounded rationality of managers and organizational constraints such as labor unionization.
Measuring and Calculating Efficiency

Two broad classes of techniques used in determining productivity impacts and efficiency metrics are parametric and nonparametric (or data envelopment analysis) techniques. The main assumptions in the nonparametric technique are that the production set is convex and that measurement and other errors in the data are negligible [2, 9, 29].

Nonparametric techniques have an advantage over parametric techniques in that no functional form is assumed. These techniques tend to outperform parametric techniques when the production process exhibits a variable returns to scale [3]. It was also found that nonparametric techniques performed well if the underlying production process was complex [16]. Similar comparisons can be found in [4, 14] and [23]. In this paper, we attempted to correlate results from the two techniques and then made inferences regarding the production technology based on the correlation results. Findings from previous research on parametric and nonparametric convergence were used to substantiate our arguments.

As explained earlier, technical efficiency is independent of the prices of inputs and measures the radial distance of the current choice of input quantities from the best practices frontier. Technical efficiency ($\theta$) is obtained by solving the following linear programming problem:

$$\begin{align*}
\min_{\theta, \lambda} & \quad \theta \\
\text{s.t.} & \quad Y \cdot \lambda \geq y^j \\
& \quad X \cdot \lambda \geq x^j \theta \\
& \quad \lambda \geq 0
\end{align*}$$

Similarly, cost efficiency can also be estimated using the cost minimization formulation given by equation (2). The minimum cost input quantity $x^j$ for the firm $j$ is the solution obtained by solving the following linear programming problem for the firm [12].

$$\begin{align*}
\min_{x^j, \lambda} & \quad p^j \cdot x^j \\
\text{s.t.} & \quad Y \cdot \lambda \geq y^j \\
& \quad X \cdot \lambda \leq x^j \\
& \quad \lambda \geq 0
\end{align*}$$

In the above equations, variables in uppercase are matrices containing data for all firms. That is, $Y$ is an $m \times n$ matrix representing $m$ outputs and $n$ firms and, $X$ is a $J \times n$ matrix corresponding to $n$ firms and $J$ inputs and $\lambda$ and $\theta$ are $1 \times n$ matrices of weights and zeroes, respectively. Variables in lowercase represent data in vector form for a firm $j$, hence the superscript $j$. Once technical and cost efficiencies have been estimated, the firm-specific allocative efficiency ($FAE$) can be calculated by dividing the cost efficiency by the technical efficiency. Appendix A.1 contains the details on how
the different types of efficiencies, including LAE, were calculated using the nonpara-
metric approach. These various efficiencies were also estimated using the parametric
approach. The parametric production function and derivations of efficiency mea-
sures using this technique are presented in Appendix A.2.

Empirical Data and Estimation

The data were obtained from the Washington State Department of Health
(WADOH) hospital database [22, 26]. These financial data spanning 1976–94 col-
lected by WADOH contains 83 accounts divided into three different categories. Two
categories comprise revenue-generating departments: (1) departments involved in
inpatient care, primarily the room and board functions, such as acute care and inten-
sive care, and (2) ancillary departments in which services are provided for both
inpatients and outpatients. Examples of ancillary departments include the emer-
gency room, pharmacy, and the x-ray lab. The third category of accounts comprises
non-revenue-generating departments (i.e., cost centers). Services such as admitting
and data processing are provided by these departments. These data include charges
and costs. Charges are the total dollars billed for patient services during the period;
they do not reflect reimbursement. Costs are the accumulated operational expenses
for the period. The cost information is broken down into components such as salaries
and wages, supplies, and rental expenses. Capital expense allocated to data process-
ing, data communication, medical records, admitting, central service, purchasing,
accounting, medical records, and personnel was categorized as IT capital. The re-
main ing capital expense (allocated to MRI, CT scan, radiology-diagnostic, radiol-
ogy-therapeutic, electrodiagnosis, nuclear medicine, emergency room, electromyo-
graphy, recovery room, anesthesiology, IV therapy, surgical service, ICU, semi-inten-
sive care, acute care, physical rehabilitation, laboratory, pharmacy, home care ser-
VICES, medical staff, etc.) was considered as non-IT (medical) capital. In accounts
where the capital was classified as IT, the salaries were aggregated as IT labor. The
salaries in the remaining accounts were classified as non-IT (medical) labor. The
rationale for this classification was based on interviews with IT managers from two
major hospitals in the Southwest. One limitation of the study, as with most IT produc-
tivity studies in the past, is the aggregation of IT into a single capital measure. This
aggregation may not inform us directly about the selection of appropriate type of IT.
However, the ideas advanced here can be used in future research in comparing pro-
ductivity results from various types of IT.

The data also contain a proxy for output measure called adjusted patient days.
Adjusted patient days are defined as the sum of inpatient days and “outpatient days.”
Outpatient days are derived by dividing outpatient revenue by inpatient revenue per
day (inpatient revenue divided by inpatient days). Menon, Lee, and Eldenburg [22]
suggest, rather than using annual investments for inputs, calculating the productive
capital by accumulating annual investments. Obsolete and retired capital over the
years were accounted for by use of a depreciation rate. These calculations are repro-
duced in appendix A.4. As explained earlier, the formulation of the system of equa-
tions requires the use of input prices. The proxy for prices is derived based on the concept of implicit rental value of an asset during its service life [22]. Appendix A.5 reproduces the derivations on the prices of input as per these papers.

Results

AFTER THE EFFICIENCY VALUES WERE ESTIMATED USING BOTH NONPARAMETRIC and parametric techniques, the efficiency rankings of hospitals from the two techniques were correlated [5]. For example, point estimates of $FAE$ for the parametric estimation were used to determine the relative ranking of the hospitals and were correlated with the rankings obtained from the estimation of $FAE$ using the nonparametric technique. The correlation of rankings between the two techniques was used to draw inferences regarding the characteristics of the “real” production function. High correlation or complete convergence could mean that the underlying production technology is simple, whereas very low convergence could mean that the production function is complex and cannot be measured well with simple techniques such as multivariate linear regression. In the tables and discussion of results, the following notation is used to describe $IAE$ for various pairs of inputs. Non-IT labor was taken as the reference factor for all $IAE$ calculations. Hence, in the paper, $IAE_1$ refers to the non-IT capital–labor pair, $IAE_2$ to the IT labor and non-IT labor pair, and $IAE_3$ refers to the IT capital and non-IT labor pair.

Correlation of Efficiency Rankings

The rank correlation between the $FAE$ from both techniques is given in Table 1. This table shows high correlation for the years 1976–82 on the $FAE$ rankings from the two techniques. In the years after 1982, the correlation is lower. Indeed, after 1990, the correlation is negative. Lower correlation values may not be symptomatic of methodological problems but may be due to the changes in the underlying production technology that affect the shape and nature of the production function. The restrictive nature of parametric formulation may not account for these changes. Technological changes such as the explosion of PC use in firms in the mid-1980s and the growth of client-server technologies in the early 1990s may have caused abrupt technical changes not captured by production functions. These groupings that we see in the results may also be influenced by regulatory changes, which significantly altered operating procedures and payment mechanisms in the health-care industry around 1983–85 and 1989–90 [21].

Similarly, the $IAE$ values (and the resulting ranks) for the sample, using the nonparametric technique, were correlated with the $IAE$ rankings obtained from the stochastic production function estimation (Table 2). Note that $IAE_2$ rankings are highly correlated between the two techniques.

Since $IAE_2$ refers to labor (IT and non-IT), this high correlation of the results may be due to both methodological and contextual factors. Labor prices and responsibilities (or marginal productivity of labor) are usually constant over the years. Decision-makers may have used good estimates of these values during resource allocation. In
Table 1. Correlation Between FAE Rankings for Parametric and Nonparametric Techniques

<table>
<thead>
<tr>
<th>Year</th>
<th>Correlation</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>0.830</td>
<td>0.0001</td>
</tr>
<tr>
<td>1977</td>
<td>0.929</td>
<td>0.0001</td>
</tr>
<tr>
<td>1978</td>
<td>0.897</td>
<td>0.0001</td>
</tr>
<tr>
<td>1979</td>
<td>0.847</td>
<td>0.0001</td>
</tr>
<tr>
<td>1980</td>
<td>0.902</td>
<td>0.0001</td>
</tr>
<tr>
<td>1981</td>
<td>0.839</td>
<td>0.0001</td>
</tr>
<tr>
<td>1982</td>
<td>0.817</td>
<td>0.0001</td>
</tr>
<tr>
<td>1983</td>
<td>0.813</td>
<td>0.0001</td>
</tr>
<tr>
<td>1984</td>
<td>0.664</td>
<td>0.0001</td>
</tr>
<tr>
<td>1985</td>
<td>0.533</td>
<td>0.0001</td>
</tr>
<tr>
<td>1986</td>
<td>0.609</td>
<td>0.0001</td>
</tr>
<tr>
<td>1987</td>
<td>0.597</td>
<td>0.0001</td>
</tr>
<tr>
<td>1988</td>
<td>0.617</td>
<td>0.0001</td>
</tr>
<tr>
<td>1989</td>
<td>0.644</td>
<td>0.0001</td>
</tr>
<tr>
<td>1990</td>
<td>0.581</td>
<td>0.0001</td>
</tr>
<tr>
<td>1991</td>
<td>-0.365</td>
<td>0.014</td>
</tr>
<tr>
<td>1992</td>
<td>-0.440</td>
<td>0.003</td>
</tr>
<tr>
<td>1993</td>
<td>0.451</td>
<td>0.0001</td>
</tr>
<tr>
<td>1994</td>
<td>0.466</td>
<td>0.0022</td>
</tr>
</tbody>
</table>

comparison, rapid advancements in IT capital, new products and new versions of existing products from vendors, and new paradigms (hierarchical to relational, client-server, object orientation, etc.) may have led to a poor estimate of marginal product of IT capital. Further, it is possible that the complementarity between non-IT labor and capital, and between non-IT labor and IT capital (or labor–capital complementarity in general) was poorly understood and had been poorly incorporated into the resource allocation decision-making process. Hence, we concluded that the results here were not entirely due to methodological factors, but actually due to factors governing productivity.

Next, we checked to see whether the rankings of the IAEs for the nonparametric technique are indeed correlated to the nonparametric FAE results. That is, is IAE any indicator of FAE? Table 3 contains the correlation of IAE rankings with the FAE rankings both obtained from the nonparametric formulation. For most of the values, the correlation is not significant. The explanation lies in the absolute prices of inputs and probably also in the price elasticities of the inputs. Since the price ranges of non-IT labor and IT labor are much closer than the price ranges of other inputs and are relatively predictable, labor may have had a small effect on FAE. This ratio has remained static over the years, unlike the ratios involving prices of IT and non-IT capital. On the other hand, if price elasticity of an input factor is high, it may have a greater effect on the FAE than an input factor with lower price elasticity. We conclude
Table 2. Correlation Between Parametric and Nonparametric IAE Rankings

<table>
<thead>
<tr>
<th>Year</th>
<th>$IAE_1$</th>
<th>$IAE_2$</th>
<th>$IAE_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>0.13 (0.40)</td>
<td>0.38 (0.01)</td>
<td>0.46 (0.003)</td>
</tr>
<tr>
<td>1977</td>
<td>-0.11 (0.46)</td>
<td>0.65 (0.0001)</td>
<td>-0.29 (0.04)</td>
</tr>
<tr>
<td>1978</td>
<td>-0.03 (0.85)</td>
<td>0.61 (0.0001)</td>
<td>-0.33 (0.02)</td>
</tr>
<tr>
<td>1979</td>
<td>-0.01 (0.94)</td>
<td>0.48 (0.0007)</td>
<td>-0.41 (0.004)</td>
</tr>
<tr>
<td>1980</td>
<td>-0.23 (0.11)</td>
<td>0.44 (0.002)</td>
<td>-0.28 (0.04)</td>
</tr>
<tr>
<td>1981</td>
<td>0.29 (0.04)</td>
<td>0.98 (0.0001)</td>
<td>0.60 (0.0001)</td>
</tr>
<tr>
<td>1982</td>
<td>-0.02 (0.85)</td>
<td>0.88 (0.0001)</td>
<td>0.39 (0.005)</td>
</tr>
<tr>
<td>1983</td>
<td>0.16 (0.27)</td>
<td>0.91 (0.0001)</td>
<td>0.36 (0.009)</td>
</tr>
<tr>
<td>1984</td>
<td>0.26 (0.07)</td>
<td>0.91 (0.0001)</td>
<td>0.64 (0.0001)</td>
</tr>
<tr>
<td>1985</td>
<td>0.15 (0.26)</td>
<td>0.94 (0.0001)</td>
<td>0.49 (0.0002)</td>
</tr>
<tr>
<td>1986</td>
<td>-0.10 (0.45)</td>
<td>0.91 (0.0001)</td>
<td>0.28 (0.04)</td>
</tr>
<tr>
<td>1987</td>
<td>0.14 (0.31)</td>
<td>0.86 (0.0001)</td>
<td>0.86 (0.0001)</td>
</tr>
<tr>
<td>1988</td>
<td>0.49 (0.0003)</td>
<td>0.92 (0.0001)</td>
<td>0.73 (0.0001)</td>
</tr>
<tr>
<td>1989</td>
<td>0.41 (0.005)</td>
<td>0.98 (0.0001)</td>
<td>0.98 (0.0001)</td>
</tr>
<tr>
<td>1990</td>
<td>0.62 (0.0001)</td>
<td>0.93 (0.0001)</td>
<td>0.49 (0.0006)</td>
</tr>
<tr>
<td>1991</td>
<td>0.23 (0.12)</td>
<td>0.71 (0.0001)</td>
<td>0.54 (0.0001)</td>
</tr>
<tr>
<td>1992</td>
<td>0.22 (0.13)</td>
<td>0.85 (0.0001)</td>
<td>0.26 (0.09)</td>
</tr>
<tr>
<td>1993</td>
<td>0.05 (0.74)</td>
<td>0.71 (0.0001)</td>
<td>-0.09 (0.57)</td>
</tr>
<tr>
<td>1994</td>
<td>0.09 (0.54)</td>
<td>0.96 (0.0001)</td>
<td>0.36 (0.02)</td>
</tr>
</tbody>
</table>

*p values are given in parentheses beside the correlation values.*

that the absolute prices are playing a larger role in efficiency than the price elasticity. The estimation of the technically efficient production frontier for the nonparametric is given in Table 4. The large $t$-values indicate overfitting, which is expected since the input mix was bereft of technical inefficiency and numerically "moved" to the production frontier. In addition, the curve seems highly elastic with respect to non-IT labor and relatively inelastic to the remaining inputs for most years.

Descriptive Statistics for Efficiency

Table 5 shows the mean, standard deviation, third-quartile, median, the range of values between third-quartile and first-quartile, and the range of values between the maximum and minimum values for the cost, technical, and allocative efficiencies determined by the nonparametric results. The range between maximum and minimum values for cost and allocative efficiencies (0.902 and 0.887, respectively) is large. However, the range between the third and first quartile is small for all efficiencies (0.227, 0.190, and 0.234, respectively). This is indicative of clusters of hospitals outperforming other clusters. The mean technical efficiency is high, indicating that from a production perspective, hospitals did well. However, when we consider costs, these hospitals could have chosen a more optimal mix of inputs. This difference
Table 3. Correlation Between IAE and FAE Rankings for Nonparametric Technique

<table>
<thead>
<tr>
<th>Year</th>
<th>IAE₁</th>
<th>IAE₂</th>
<th>IAE₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>0.02(0.89)</td>
<td>0.02(0.89)</td>
<td>0.41(0.007)</td>
</tr>
<tr>
<td>1977</td>
<td>-0.32(0.03)</td>
<td>0.21(0.15)</td>
<td>-0.17(0.24)</td>
</tr>
<tr>
<td>1978</td>
<td>-0.20(0.17)</td>
<td>0.17(0.22)</td>
<td>-0.12(0.42)</td>
</tr>
<tr>
<td>1979</td>
<td>-0.17(0.23)</td>
<td>0.38(0.007)</td>
<td>-0.17(0.25)</td>
</tr>
<tr>
<td>1980</td>
<td>-0.31(0.03)</td>
<td>0.42(0.002)</td>
<td>-0.27(0.06)</td>
</tr>
<tr>
<td>1981</td>
<td>-0.17(0.26)</td>
<td>0.11(0.47)</td>
<td>0.24(0.10)</td>
</tr>
<tr>
<td>1982</td>
<td>-0.67(0.0001)</td>
<td>-0.07(0.62)</td>
<td>-0.32(0.02)</td>
</tr>
<tr>
<td>1983</td>
<td>-0.53(0.0001)</td>
<td>-0.20(0.15)</td>
<td>-0.18(0.21)</td>
</tr>
<tr>
<td>1984</td>
<td>-0.57(0.0001)</td>
<td>0.02(0.84)</td>
<td>0.05(0.73)</td>
</tr>
<tr>
<td>1985</td>
<td>-0.53(0.0001)</td>
<td>-0.08(0.56)</td>
<td>-0.45(0.0006)</td>
</tr>
<tr>
<td>1986</td>
<td>-0.48(0.0002)</td>
<td>-0.25(0.07)</td>
<td>-0.14(0.29)</td>
</tr>
<tr>
<td>1987</td>
<td>0.09(0.51)</td>
<td>-0.14(0.31)</td>
<td>-0.16(0.25)</td>
</tr>
<tr>
<td>1988</td>
<td>0.12(0.42)</td>
<td>-0.19(0.18)</td>
<td>-0.02(0.90)</td>
</tr>
<tr>
<td>1989</td>
<td>-0.10(0.48)</td>
<td>-0.07(0.62)</td>
<td>0.02(0.85)</td>
</tr>
<tr>
<td>1990</td>
<td>0.05(0.75)</td>
<td>0.05(0.74)</td>
<td>-0.19(0.19)</td>
</tr>
<tr>
<td>1991</td>
<td>0.34(0.02)</td>
<td>-0.32(0.03)</td>
<td>-0.11(0.46)</td>
</tr>
<tr>
<td>1992</td>
<td>0.20(0.17)</td>
<td>-0.006(0.97)</td>
<td>0.26(0.09)</td>
</tr>
<tr>
<td>1993</td>
<td>-0.41(0.007)</td>
<td>0.006(0.97)</td>
<td>-0.60(0.0001)</td>
</tr>
<tr>
<td>1994</td>
<td>-0.18(0.25)</td>
<td>0.10(0.53)</td>
<td>-0.18(0.25)</td>
</tr>
</tbody>
</table>

*p values are given in parentheses beside the correlation values.*

...between considering inputs as costs or as quantities could help explain conflicting results in previous IT productivity research.

We see that more hospitals were technically efficient than were cost efficient. In addition, hospitals were consistently either high or low performers (in terms of cost efficiency) over the years. This is indicative of lower allocative efficiency in the sample. That is, although productivity may have increased, the choice of input quantities based on their prices was suboptimal. This may be due to poor "learning" of the marginal products of inputs.

High values for technical efficiency may be attributed, among other causal factors, to the complementarity between inputs. Complementarity effects enhance the productive contribution among inputs [24]. For example, IT capital contributes to the productivity of medical equipment because data generated by this equipment is captured and reported more effectively using IT.

Firm and Year Effects

A multivariate analysis of variance of cost efficiency values was conducted using the year and firm as the fixed effects factors. Interaction effect could not be studied because of insufficient degrees of freedom. The results are shown in Table 6. The
Table 4. Estimate of the Production Frontier for Nonparametric Technique

<table>
<thead>
<tr>
<th>Year</th>
<th>$\ln(a_0)$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>6.40(0.23)</td>
<td>0.75(0.04)</td>
<td>-0.04(0.01)</td>
<td>0.32(0.04)</td>
<td>-0.006(0.004)*</td>
</tr>
<tr>
<td>1977</td>
<td>4.61(0.21)</td>
<td>1.03(0.02)</td>
<td>0.07(0.03)</td>
<td>-0.04(0.02)</td>
<td>-0.07(0.02)</td>
</tr>
<tr>
<td>1978</td>
<td>6.57(0.18)</td>
<td>1.12(0.02)</td>
<td>-0.23(0.03)</td>
<td>0.04(0.02)</td>
<td>0.07(0.01)</td>
</tr>
<tr>
<td>1979</td>
<td>5.93(0.16)</td>
<td>1.12(0.02)</td>
<td>-0.18(0.02)</td>
<td>0.01(0.02)*</td>
<td>0.06(0.02)</td>
</tr>
<tr>
<td>1980</td>
<td>6.03(0.22)</td>
<td>1.09(0.02)</td>
<td>-0.11(0.03)</td>
<td>0.01(0.02)*</td>
<td>-0.02(0.02)*</td>
</tr>
<tr>
<td>1981</td>
<td>5.08(0.36)</td>
<td>1.09(0.24)</td>
<td>-0.09(0.03)</td>
<td>0.05(0.02)</td>
<td>0.03(0.02)*</td>
</tr>
<tr>
<td>1982</td>
<td>5.16(0.36)</td>
<td>1.11(0.03)</td>
<td>-0.11(0.03)</td>
<td>-0.002(0.01)*</td>
<td>0.04(0.01)</td>
</tr>
<tr>
<td>1983</td>
<td>4.80(0.19)</td>
<td>1.05(0.04)</td>
<td>-0.056(0.02)</td>
<td>0.028(0.02)*</td>
<td>-0.027(0.01)</td>
</tr>
<tr>
<td>1984</td>
<td>4.06(0.18)</td>
<td>0.837(0.02)</td>
<td>0.072(0.02)</td>
<td>0.096(0.01)</td>
<td>0.01(0.01)*</td>
</tr>
<tr>
<td>1985</td>
<td>4.88(0.31)</td>
<td>0.91(0.04)</td>
<td>-0.034(0.03)*</td>
<td>0.118(0.02)</td>
<td>0.036(0.01)</td>
</tr>
<tr>
<td>1986</td>
<td>6.01(0.55)</td>
<td>1.07(0.06)</td>
<td>-0.08(0.05)*</td>
<td>0.140(0.04)</td>
<td>-0.06(0.02)</td>
</tr>
<tr>
<td>1987</td>
<td>3.68(0.65)</td>
<td>0.97(0.07)</td>
<td>0.01(0.04)*</td>
<td>0.10(0.05)</td>
<td>0.05(0.02)</td>
</tr>
<tr>
<td>1988</td>
<td>3.43(0.42)</td>
<td>0.93(0.06)</td>
<td>0.04(0.03)*</td>
<td>0.12(0.05)</td>
<td>0.04(0.03)*</td>
</tr>
<tr>
<td>1989</td>
<td>2.90(0.49)</td>
<td>0.94(0.05)</td>
<td>0.04(0.04)*</td>
<td>0.142(0.04)</td>
<td>0.069(0.03)</td>
</tr>
<tr>
<td>1990</td>
<td>2.47(0.52)</td>
<td>0.93(0.05)</td>
<td>0.08(0.04)</td>
<td>0.09(0.02)</td>
<td>0.06(0.03)</td>
</tr>
<tr>
<td>1991</td>
<td>0.62(0.58)*</td>
<td>0.73(0.07)</td>
<td>0.22(0.05)</td>
<td>0.05(0.04)*</td>
<td>0.11(0.03)</td>
</tr>
<tr>
<td>1992</td>
<td>-0.18(0.98)*</td>
<td>0.89(0.11)</td>
<td>0.26(0.07)</td>
<td>-0.03(0.09)*</td>
<td>0.06(0.04)*</td>
</tr>
<tr>
<td>1993</td>
<td>4.53(1.78)</td>
<td>1.63(0.13)</td>
<td>-0.34(0.11)</td>
<td>-0.44(0.11)</td>
<td>0.22(0.09)</td>
</tr>
<tr>
<td>1994</td>
<td>3.37(0.91)</td>
<td>1.15(0.08)</td>
<td>0.01(0.07)*</td>
<td>0.02(0.07)*</td>
<td>-0.01(0.04)*</td>
</tr>
</tbody>
</table>

$t$ statistics are given in parentheses. * indicates that the estimate is not significant.

Table 5. Descriptive Statistics for Efficiencies Obtained from Nonparametric Technique

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>3d quartile</th>
<th>Median</th>
<th>Q3–Q1</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost efficiency</td>
<td>0.579</td>
<td>0.176</td>
<td>0.682</td>
<td>0.571</td>
<td>0.227</td>
<td>0.902</td>
</tr>
<tr>
<td>Technical efficiency</td>
<td>0.848</td>
<td>0.126</td>
<td>0.960</td>
<td>0.860</td>
<td>0.190</td>
<td>0.600</td>
</tr>
<tr>
<td>Firm-wise allocative efficiency</td>
<td>0.681</td>
<td>0.168</td>
<td>0.804</td>
<td>0.676</td>
<td>0.234</td>
<td>0.887</td>
</tr>
</tbody>
</table>

Statistic of interest is Wilks's lambda [18]. The $F$-value for this statistic indicates that the null hypothesis (there are no factor effects) is rejected. This result is not surprising, particularly in the health-care area. The time period under study was characterized by several regulatory changes and by mostly reactionary decision-making in resource allocation throughout the industry. Furthermore, the presence of systematic firmwise effects is due to the static nature of "culture" in hospitals, particularly in resource allocation and budgeting, which is also not a very surprising result. These results, however, indicate the need to model firm and year effects explicitly, since
Table 6. Firm and Year Effects in Cost Efficiency

<table>
<thead>
<tr>
<th>Factor</th>
<th>Wilks’s lambda</th>
<th>F value</th>
<th>Null hypothesis (No effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year effects</td>
<td>0.4513</td>
<td>13.850</td>
<td>Rejected</td>
</tr>
<tr>
<td>Firm effects</td>
<td>0.2025</td>
<td>10.296</td>
<td>Rejected</td>
</tr>
</tbody>
</table>

Table 7. Clustering Observation by Efficiency Values and IT Investment

<table>
<thead>
<tr>
<th>Efficiency (cluster mean)</th>
<th>IT capital (cluster mean)</th>
<th>IT labor (cluster mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.96562</td>
<td>-0.12441</td>
<td>-0.00475</td>
</tr>
<tr>
<td>-0.69966</td>
<td>-0.30482</td>
<td>-0.40079</td>
</tr>
<tr>
<td>-0.29280</td>
<td>2.18342</td>
<td>2.33224</td>
</tr>
<tr>
<td>Technical efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.23022</td>
<td>-0.34466</td>
<td>-0.38916</td>
</tr>
<tr>
<td>1.12468</td>
<td>2.99377</td>
<td>3.18850</td>
</tr>
<tr>
<td>-1.55846</td>
<td>0.57401</td>
<td>0.79195</td>
</tr>
</tbody>
</table>

production characteristics such as productivity and efficiency are greatly influenced by them. By pooling data across years, we average out the efficiency gains over the years from learning or from other factors.

Overinvestment in IT and Efficiency

Cluster analysis was used as an exploratory technique to determine the pattern of investment levels and efficiency. We attempted to cluster hospitals based on cost and technical efficiency values and used input factors as the variables for clustering observations. By doing so, we could infer about the link between input usage and efficiency in hospitals. All input quantities were normalized to a mean of zero and standard deviation of one as recommended in the literature [18]. Outliers were "trimmed" to avoid confounding the estimation [27]. First, seven clusters were created that were then restricted to three by further dropping outliers. About 1,203 observations were classified into three categories that were statistically significant. For each cluster, the mean cost efficiency was determined. The results of clustering are presented in Table 7. Only one cluster of observations has a mean cost efficiency (0.965) greater than zero. For this cluster, the mean IT capital and labor is close to zero (probably close to optimal) indicating that cost-efficient hospitals neither overused nor underused IT. In the clusters based on technical efficiency, we see that efficient
hospitals (mean 1.124) used more IT capital and labor. Mean IT capital for this cluster is 2.99 and that for IT labor is 3.18.

Discussion

PROCESS INEFFICIENCIES ARE CAUSED BY VARIOUS FACTORS, INCLUDING POOR demand estimation, information technology (IT) misalignment, and poor understanding of the capabilities of organizational resources. A study like this can help practitioners locate the main sources of inefficiencies of the production process and its relationship to the deployment of IT and other capital.

Efficiency of production is an important managerial goal. Downsizing illustrates this point well. Questions such as whether managers should reduce labor forces when employing more IT or whether they should eliminate production facilities by embracing more outsourcing strategies address efficiency issues. Except for a few recent studies, many prior studies have failed to link IT investment to productivity enhancement. Given frequent paradigm shifts in IT evolution, and the lag between IT investment and utilization of their full potential, we may speculate that organizations are still “learning” how to take advantage of technology but have not yet reached the mature stage of IT use. However, if IT reduces inefficiencies, we may envision that productivity effects will surface in the future. Hence, investigating the relationship between IT investment level and inefficiencies enabled us empirically to test this transient yet positive movement toward the productivity stage. More important, this has helped us to gauge the nature of transformation in business processes triggered by IT. With our results, we validated the position that inefficiencies are inherent in firms and that the systematic biases arising as a result of these inefficiencies must be controlled for in order to obtain more reliable productivity measures. Further, there were significant changes in the underlying production function over the years due to changes initiated in firms. We also showed that, while hospitals may have been efficient in their operations, resource allocation may have been inefficient. Low allocative efficiency and the resulting low cost efficiency, in spite of high technical efficiency, is indicative of this malaise. We list below other inferences from this study.

Change in Production Function

Using simulation studies, Bjurek et al. [5] found that if the stochastic production function was formulated close to the actual production function, stochastic production performed much better than DEA. The reverse was found to be true if the stochastic production function was not close to the actual production function. Banker et al. [3] found that returns to scale determined how much better DEA would perform over translog production formulation. Here, the value for returns to scale (the sum of coefficients of inputs) is found to be a little over one for each year (Table 8) and so, the returns to scale may not be affecting the change in correlation in our sample. Hence, the divergence in our results from the two techniques may have stemmed from the change in the underlying production functions. Around 1983, the prospective
Table 8. Estimate of the Production Frontier for Stochastic Technique
Pooled over Years

<table>
<thead>
<tr>
<th>Year</th>
<th>Constant</th>
<th>Non-IT labor</th>
<th>Non-IT capital</th>
<th>IT labor</th>
<th>IT capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976–83</td>
<td>4.75 (0.69)</td>
<td>0.998 (0.013)</td>
<td>0.0001 (0.0003)</td>
<td>-0.0122 (0.00004)</td>
<td>0.0009 0.00005)</td>
</tr>
<tr>
<td>1984–90</td>
<td>3.87 (0.121)</td>
<td>0.734 (0.04)</td>
<td>0.223 (0.006)</td>
<td>-0.014 (0.0004)</td>
<td>0.0115 (0.0005)</td>
</tr>
<tr>
<td>1991–94</td>
<td>4.27 (0.131)</td>
<td>1.03 (0.013)</td>
<td>0.0455 (0.0012)</td>
<td>-0.0115 (0.0004)</td>
<td>0.0019 (0.00001)</td>
</tr>
</tbody>
</table>

$t$ statistics are reported in parentheses. Note that all estimates are significant.

payment system for Medicare and Medicaid patients was instituted by the federal
and most state governments, which may have changed the production process and
the investment pattern [21]. The focus of the hospitals was found to have shifted to
reducing inpatient stays [11]. Change in production strategy, such as priority among
various outputs, affects production technology. Most previous empirical studies in
MIS have assumed disembedded technical change, which is that production function
maintains the same basic form as time elapses. If this assumption does not hold as
indicated by our results, researchers face the more challenging task of attempting to
identify the nature of technical progress. Our results showed that the production
function did change over time indicated by the change in parameter estimates, par-
ticularly for non-IT capital (Table 8). Table 8 shows the estimates of the parameters of
the stochastic production function for each year pooled into three groups of years—
1976 to 1983, 1984 to 1990 and 1991 to 1994—groups indicated by the pattern in
the $FAE$ estimates in Table 1.

Accelerating IT Investments in the 1980s

Two characteristics of IT may have led to large allocative and cost inefficiency in
production. First, IT price per physical unit was lower compared to other production
inputs and also decreasing a rapid pace. Second, accelerating investments and low
prices together produced large input units for IT. This combination may have caused
the apparent inefficiency in the allocation of budget resources to other inputs.

Differences from Previous Work

As discussed above, Table 8 shows that while IT capital shows positive contribution,
this is not the case for IT labor. IT labor shows negative contribution contradicting
previous findings in this area (e.g., [15]). Further, non-IT capital showed a greater
contribution than shown by several authors. The difference may have resulted be-
cause [15] and others pooled data from various industries, so that the non-IT capital
has different meanings in the sample. In our case, the sample consists only of hospi-
tals. This ensures that non-IT capital is consistently medical capital. Since medical
capital usage is central to hospital activities, its contribution to productivity would
be higher than IT contribution. On the other hand, it may also be argued that the results here cannot be directly generalized to other industries because of the specificity of non-IT capital in hospitals.

Conclusion

THE GOALS OF THIS PAPER INCLUDED: (i) ESTIMATING IT PRODUCTIVITY contribution, (ii) studying inefficiencies in hospitals and how IT affects inefficiencies, and (iii) characterizing the nature of production technology changes in hospitals (or business processes, in general). It is possible that as IT use matures, productivity gains may be directly observable. Until then, the lag in understanding IT capabilities will lead to inefficiencies that may also show up as poor productivity in empirical studies. We used results from two techniques to infer characteristics about the underlying production technology and its relation to IT investments.

We surmised that there were three periods of technical similarities in production in hospitals between 1976 and 1994. These periods seem to coincide with changes in IT paradigms. However, it is also possible that regulatory and other environmental forces may have affected the data and the result [21]. We also found that while hospitals were technically efficient, they may have overinvested in IT. This was evidenced by low cost efficiencies in our sample. A limitation of the study, as noted earlier, is that the aggregation may not completely reveal productivity impacts of inputs. Furthermore, the results may not be generalizable to other industries owing to the specific nature of the healthcare industry and IT deployment in the industry. Future research must not only focus on types of IT investments, but also control for inefficiencies and other factors that affect the production process.

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Appendix A: Mathematical and Technical Notes

A.1. Cost, Technical, and Allocative Efficiency in a Nonparametric Case

Let the input mix used by a firm \( j \) be given by \( x^j \) and prices of the inputs by the vector \( p^j \). If \( x_0^j \) is the minimum cost input quantities required to produce the same output level, then cost efficiency \( C.E. \) is defined as

\[
C.E. = \frac{p^j \cdot x_0^j}{p^j \cdot x^j}.
\]

The equations for the cost efficiency and technical efficiency were presented in the article. In DEA literature, this problem is rewritten (e.g. [9], p. 37) as

\[
\begin{align*}
\min_{\theta, s^+, s^-} & \quad \theta - \varepsilon \cdot s^+ - \varepsilon \cdot 1s^- \\
\text{s.t.} & \quad Y \cdot \lambda - s^+ - y^j = 0 \\
& \quad x^j \cdot \theta - X \cdot \lambda - s^- = 0
\end{align*}
\]

The variables \( s^+ \) and \( s^- \) represent output and input slacks, respectively. \( \varepsilon \) is a constant, infinitesimal non-Archimedean number. To avoid numerical problems due to the choice of \( \varepsilon \) in standard mathematical programming software, the LP is solved in two stages (see [9], p. 32). First, optimal \( \lambda \) is determined, and in the second stage the slack variables are determined.

Once cost efficiency and technical efficiencies have been estimated, firmwise allocative efficiency can be calculated by

\[
FAE = \frac{C.E.}{\theta}.
\]

In order to estimate the IAE for the nonparametric case, we followed the following steps. First, the set of all points on the technically efficient frontier was found by radially reducing the input quantities by \( \theta \) and subtracting the slack. The graph of these points is fit to a model given by equation (6), which is similar to the Cobb-Douglas function but is being used in a curve-fitting sense.

\[
\ln y = a_0 + \sum_{j=1}^{4} a_j \ln x_j.
\]

Once the technically efficient frontier is estimated through curve-fitting, the marginal product for each input is estimated by calculating the slope of the above equation with respect to that input. Finally, the ratios of marginal products can be divided by the ratios of the prices of inputs to give us the IAE estimates.
A.2. Parametric Production Function and Stochastic Formulation

The Cobb-Douglas production function is the most often used parametric formulation and is given by

\[ Y = a_0 \prod_{i \in J} (z_i^{a_i}) , \]

where \( J \) is the number of inputs, \( z \) represent an input factor, and \( Y \) is the output. This function satisfies the basic properties of a production function. While more flexible functional forms such as translog, generalized Leontief, general linear, and generalized quadratic forms have gained more attention in recent studies, the Cobb-Douglas formulation is commonly used because functions such as translog cannot incorporate IAE easily. See [8] for reasons for this and other limitations in the flexible production and cost functions. The Cobb-Douglas formulation is empirically estimated in its logarithmic form, which is

\[ \ln Y = \ln a_0 + \sum_{i \in I} (a_i \ln z_i) . \]

The first-order conditions for cost minimization are:

\[ \bar{y} = f(\bar{z}) \]

\[ \frac{f_i(\bar{z})}{f_j(\bar{z})} = \frac{w_i}{w_j} \forall i = 1, \ldots, n, i \neq j , \]

where \( f(\bar{z}) \) refers to the partial of \( f(\bar{z}) \) with respect to \( z_i \). Substituting (7) into the first-order conditions (10) for cost minimizing yields the following set of equations:

\[ \frac{a_i z_j}{a_j z_i} = \frac{p_i}{p_j} \forall i \neq j , \]

which can be rewritten in logarithmic form as

\[ \ln a_i + \ln z_j - \ln a_j - \ln z_i = \ln p_i - \ln p_j . \]

The entire set of equations (11) and (12) can be empirically estimated. In order to introduce technical and allocative inefficiencies in these equations, they are modified in the following manner. A composite error term \( u - \nu \) is introduced into equation (12) such that \( u \) is a random error term with mean zero, whereas \( \nu > 0 \) is an error term distributed truncated normal representing technical inefficiency. In addition, error terms \( \psi_j \) are introduced into equation (11) to model allocative inefficiency.
Thus, the Cobb-Douglas function is rewritten as

\[ Y = a_0 \prod_{j \in J} (z_j^{\alpha_j}) e^{u-y}, \]

and first-order conditions above rewritten with the allocative inefficiency term,

\[ \frac{a_j z_j}{a_i z_i} = \frac{p_i e^{r_i}}{p_j} \forall i \neq j. \]

The parametric formulation characterized by the likelihood function in appendix A.3 and by the system of equations in appendix A.2 (equations 11 and 12) was estimated to determine the parameters of the production function. The parameter estimates were then used to calculate the efficiency values for the parametric case. The nonparametric formulation that appears in equations (2) and (4) was estimated to determine the efficiency values for the nonparametric case. In both cases, the production frontiers were estimated for each year.

For an allocatively efficient input mix, \( x_j^* (\forall j \neq 1) \) can be written using equation (11), in terms of \( x_0^1 \), as

\[ x_0^j = \frac{a_j p_j}{a_i p_j} x_0^1, \]

and for an allocatively inefficient mix that is technically efficient, we write

\[ x^j = \frac{a_j p_1}{a_i p_j} x^1 e^{-\psi_i}. \]

Substituting in (5) and simplifying, we get:

\[ FAE = \frac{1}{\theta} \frac{x^1}{x_0^1 a_i + \sum_{i}^k a_i^j e^{\psi_i-j}}. \]

\( x_0^1 \), the argument minimizing the cost function, is calculated as a function of output, prices, and parameters given in (18).

\[ x_0^1 = \left[ \frac{y}{a_0} \sum_{j}^k \left( \frac{a_i p_j}{a_j p_1} \right) \right]^{-\frac{1}{\sum_i^k a_j}}. \]
A.3. Estimation Procedure for Stochastic Frontier

The introduction of technical and allocative inefficiency terms necessitates the use of a log likelihood function due to the varying distribution assumptions on these terms. Schmidt and Lovell have shown that the parameters of the production function can be estimated using the following maximum likelihood expression [28]. We use the ML function in TSP software to estimate the expression empirically.

\[
-\ln(\sqrt{\sigma_v^2 + \sigma_u^2}) - \frac{1}{2} \ln(\Sigma) + \ln(\Sigma_i(a_i)) - \frac{1}{2} \epsilon \Sigma \epsilon
\]

\[
- \frac{u - v}{\sqrt{\sigma_v^2 + \sigma_u^2}} + \ln(1 - F(\frac{\sigma_u}{\sqrt{\sigma_v^2 + \sigma_u^2}})),
\]

where \( \sigma_u \) and \( \sigma_v \) are the standard deviations of \( u \) and \( v \), respectively, and are also parameters to be estimated, \( \epsilon \) is a vector of error terms from equations (12), and \( \Sigma \) is correlation matrix of error terms.

A.4. Calculation of Capital Stock

We define capital stock as the useful capital accumulated by the firm from past and current investments. Capital stock operationalizes the true capability of the firm in terms of productive assets, unlike annual investments, which only reflect the assets acquired during a particular year [22]. A measure of the productive capital stock in a firm is given by

\[
C_t = C_{t-1} + NI_t - D_t,
\]

where \( C_t \), the capital stock in the current year \( t \), is the equal to the capital stock of the previous year \( C_{t-1} \) augmented by the new capital purchased in the current year \( NI_t \), but decremented by some portion \( D_t \) of capital that has been "retired" or depreciated.

A.5 Input Price and Quantity Calculation

Disregarding inflation and taxes, the rental price, \( p_i' \), of capital may be written as

\[
p_i' = q_i'(r_i' + d'),
\]

where \( q_i' \) is the price index of the asset for the year \( t \), \( r_i' \) is an annual rate of return for unit \( i \) which depends on the income and expenses for the unit, and \( d' \) is the annual depreciation rate. The economic implication in equation (21) is that "user cost,"
$p^t$ represents "the amount of rent that would have to be charged in order to cover costs of $q^t$ dollars' worth of an asset," based on the firm's rational decision to "buy or rent."

Furthermore, based on separate price equations such as equation (21) for each asset, rate of return for the hospital is calculated by

$$r^t_i = \frac{(I^t_i - \sum_{A=1}^{3} [P_{iA}^t \cdot d_A^t \cdot C_{iA}^t - (P_{iA}^t - P_{iA}^{t-1}) \cdot C_{iA}^t])}{\sum_{A=1}^{3} [P_{iA}^{t-1} \cdot C_{iA}^t]},$$

where $i$ indexes the hospital, $t$ indexes the year and $A$ the capital category. $I^t_i$ is the capital income defined by revenues minus operating expenses and $C_{iA}^t$ is the capital stock in asset $A$ for the unit $i$ for the year $t$. The annual operating expense is the sum of the annual capital depreciation (not capital stock), salaries, supplies and rental/lease expenses.

The price indices $q_A^t$ and the rates of depreciation $d_A^t$ were obtained from WEFA 1997 [22]. The rate of return estimated is substituted into the equation (21) to yield the rental price of each asset for each hospital for each year.