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ON THE UTILIZATION OF RESOURCES: PERSPECTIVES FROM THE U.S. TELECOMMUNICATIONS INDUSTRY

SUMIT K. MAJUMDAR*
The Management School, Imperial College of Science, Technology and Medicine, London, U.K.

The issue of resource utilization is important in the resource-based stream of work, since the ability of firms to utilize resources is a key indicator of their competitive abilities. This paper specifies why some firms might be better at utilizing resources than others. Thereafter, it demonstrates how to empirically ascertain differences in resource utilization patterns between firms using the U.S. telecommunications industry as a context. The data envelopment analysis procedure (DEA), which is a firm-level resource utilization measure, is used. This procedure can be useful for the resource-based approach research agenda since performance is measured in resource terms. DEA is applied to measure variations in different dimensions of resource utilization for the firms making up the local operating sector of the telecommunications industry. The use of DEA to guide empirical research and address theoretical issues within the resource-based paradigm is illustrated, using the resource utilization index for the telecommunications firms as the measure of strategic performance.

INTRODUCTION

The major idea behind a stream of literature which has evolved over the last decade is that the resources possessed by a firm, which are managed idiosyncratically, yield competitive advantages for some firms (Barney, 1986; Grant, 1991; Prahalad and Hamel, 1990; Rumelt, 1984; Wernerfelt, 1984). Williamson (1991) classifies the resource-based stream as the strategizing stream. He goes on to say:

> I maintain that a strategizing effort will rarely prevail if a program is burdened by significant cost excess in production, distribution, or organization. All the clever ploys and positioning, aye, all the King's horses and all the King's men, will rarely save a project that is seriously flawed in first-order economizing respects. Accordingly, I advance the argument that economizing is more fundamental than strategizing—or, put differently, that economy is the best strategy. (1991: 75–76)

While Williamson's statement is strong, the ability of firms to minimize costs does form a part of the resource-based view (Peteraf, 1993) since productive use of accumulated resources is of major consequence for attaining competitive advantage (Rumelt, 1984). This implies that the function of resource utilization is important in a resource-based perspective, along with the functions of resource accumulation and capability building, since capabilities of management are also revealed by firms' efficiencies (Hall and Winsten, 1959).

The comments by Williamson draw attention to a gap in the literature. Strategy research is concerned about performance (Chakravarthy, 1986; Lenz, 1981); however, not enough attention has been paid to performance measurement issues in the resource-based approach. It is likely that the heterogeneity assumption in the literature has

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*Correspondence to: Sumit K. Majumdar, The Management School, Imperial College of Science, Technology and Medicine, 53 Princes Gate, Exhibition Road, London SW7 2PG, U.K.

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withheld attempts to measure performance because successful performance can arise for many strategic reasons. Analyzing efficiency in resource utilization, however, reveals skill in the use of the resources. Such skill produces lasting benefits in terms of outcomes such as new product introductions or investment that can be made with the resources that are accumulated because of competent usage (Dierickx and Cool, 1989; Porter, 1996).

This paper addresses the issue of why resource utilization differences might exist between firms. Superior firms are likely to have better strategies for resource utilization; a question is: what are some of the mechanisms for resource utilization? The first part of the paper attempts to specify why some firms might be better at utilizing resources than others, using a telecommunications industry context and examples from other industries to underpin the discussion. A related empirical issue is whether differences exist in the resource utilization patterns between firms. Provided indices identifying firm-level resource utilization patterns can be developed, then variations in these indices can be explained by differences in firms' skills with respect to utilizing the resources.[1]

In the paper the data envelopment analysis procedure (DEA) which computes a firm-level resource utilization measure is used to ascertain differences in resource utilization between firms. This procedure permits empirical research in the resource-based approach, since performance is measured in resource terms. DEA has been applied to evaluate resource-usage efficiency in a variety of settings (airlines (Schefczyk, 1993), baseball players (Howard and Miller, 1993), educational programs (Charnes, Cooper, and Rhodes, 1981), schools (Ray, 1991)), but there has been marginal diffusion into the management literature.

DEA is applied to illustrate patterns of resource utilization for firms making up the local operating sector of the U.S. telecommunications industry, primarily using cross-sectional data for 1990, but also using data over a 16-year period between 1975 and 1990. These firms belong to one sector of the telecommunications industry. Therefore, patterns of product–market strategies, factor–market activities to mobilize resources and the integration of the resources may be comparable and imitable among the firms; yet, resource utilization differences may exist.

While the paper argues that intrafirm skills influence firm-level resource utilization patterns, the empirical analysis is necessarily restricted. The DEA indices only provide a first-order indication of skills in using a particular resource mix, with the mix of inputs or outputs representing firms' skills acquisition and deployment strategies. Further analysis of these indices can extend empirical research in the resource-based paradigm. For example, given the telecommunications context, exogenous factors which can impact firms' resource utilization are customer composition, urban vs. rural mix and regulatory regime characteristics. Among the firm-related factors are size, age of firm, quality of installed base, employee unionization, and aspects of past history. These have to be subsequently factored into second-stage regression models to explain cross-sectional and timewise efficiency variations.

RESOURCE UTILIZATION

The role of coordination

The key activities of a firm are resource mobilization and their organizational integration (Penrose, 1995; Richardson, 1972). A postulate in the resource-based approach is that superior performance arises because of heterogeneity (Barney, 1991; Rumelt, 1991) and uncertain inimitability (Lippman and Rumelt, 1982).[2] The resources that a successful firm possesses may be sought to be acquired by other firms, if knowledge about these diffuses easily. For example, once market successes by bond traders in an investment bank become known other investment banks can try to lure away these traders. Also, copying of many of the skill-sets of a successful

[1] One firm may be superior to another not only because of differences in the resource mix but these differences in resource mix arise because one particular strategy demands a particular resource mix; therefore, evidence of better resource utilization for a firm may be reflective of the fact that its strategies are also superior.

[2] Success in creating heterogeneity arises due to information asymmetries and luck (Barney, 1986), search acumen in resource identification and acquisition (Dierickx and Cool, 1989), mechanisms providing protection from imitation (Rumelt, 1984), and because resources, particularly human and organizational resources, are not mobile between firms. See Mahoney and Pandian (1992) and Teece, Pisano, and Shuen (1997) for reviews of extant literature.

firm may be attempted by other firms because of a bandwagon process (Mahajan, Bettis, and Sharma, 1988).[3] For example, General Motor's divisional organizational structure has been widely copied. One reason why heterogeneity among firms occurs or there are resource utilization differences is because of the existence of a unique coordination process within firms.

Coordination involves allocation of specific resources towards activities that take place. Thereafter, the function of identifying how an activity may impact on others becomes important (Kaldor, 1934), so that interdependent resources can be optimally combined together via activities. Routines help mediate such interdependencies and are characterized by explicit rules as well as tacit responses made on the basis of implicit reactions;[4] but routines are lower-order organizational abilities in undertaking activities (Nelson, 1991). The analogous higher-order skill that enables a firm to be more successful than its counterparts is in coordination, which initially involves the allocation of resources as well as the assessment of activity interdependencies.

Furthermore, social complexity exists among bundles of resources, and how people behave within organizations is a source of competitive advantage (Barney and Zajac, 1994). Resources include physical, intangible human and organizational resources. The latter are people-embodied and invisible (Itami, 1987). Given cause–effect ambiguity[5] in how socially complex resources are translated into outcomes, the coordinating function brings physical and socially complex intangible resources together. These resources are transformed into tangible outputs via identification of activities and combination of resources. With a smaller amount of resources, if a firm is able to use socially complex resources to yield relatively more output than the output attained by comparable firms, its coordination skills may be considered superior. Such a firm is not only able to exploit the strictly technical efficiencies possible, but maximize collective efficiencies arising from the interaction of physical and human resources within a given organization (Penrose, 1995).

Coordination involves the orchestration of interaction between physical and human resources. It aligns resources to be combined in a cooperative manner (Hoenack, 1983), exploiting technical and behavioral interdependencies. While firms own physical assets, with socially complex resource pools management has to be allowed access for such resources to be used (Barnard, 1968). How human capital is volunteered in undertaking activities, in conjunction with physical assets, is a function of the convergence of expectations (Malmgren, 1961) as well as economic incentives based on the exploitation of property rights accruing to resource owners (Moore, 1992). The coordination process also ensures that the expectations of persons who need to interact in the production process are aligned (Coase, 1937). Figure 1 sketches the logic articulated in the previous paragraphs.

Focal industry example

The ideas advanced in the previous paragraphs can be illustrated using the local operating companies as the focal industry to study the hypothesis that *there will be differences in resource utilization between the telecommunications firms.* These companies can use different combinations of their resources, such as switches, lines and employees, to supply outputs and have different ways of undertaking the coordination process. There can be alternate strategies to use the firms' inputs. With the advent of electronic switching, resources have become fungible and choices can be made to use technological capital such as lines or switches vs. human capital. For example, electronic switches carry out housekeeping tasks which can also be done manually (Antonelli, 1991). A local operating company can assign staff to developing switching programs rather than for record-keeping of use of switches. This switching program development can take place in a group setting difficult to emulate by other companies. Codes incorporated within switches can perform routine accounting and record-keeping functions. Another company may allocate its staff resources for low value-added accounting

[3] There are a number of site-specific physical resources, such as an oil well, which are exhaustible but are unique, cannot be replicated and provide rents by virtue of such uniqueness.
[4] For example, Polanyi (1958) has an example of the Hungarians unable to operate a light-bulb machine identical to one operating flawlessly in Austria.
[5] The issue of causal ambiguity has received attention in the literature (Alchian, 1950; Rumelt, 1984). It exists when the link, or relationship, between the resources possessed by a firm and its performance is not completely understood or specifiable (Barney, 1991).

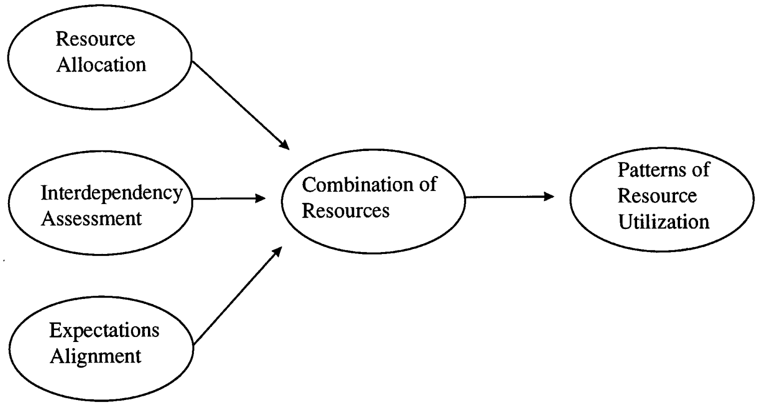

Figure 1. Components of coordination

and record-keeping duties. Hence, how human resources are coordinated within the firms can lead to efficiency differences.

Between switches and lines there are possibilities for alternate usage strategies. The deployment of fiber-optic cables, in conjunction with the use of electronic switching, means that a number of system-management tasks handled by expensive switches can be taken over by cheaper smart lines. These are lines with software codes incorporated within them at specified points; these lines function as mini-switches for handling basic line allocation and calling functions (Green, 1992). The use of such lines reduces the use of switches for basic calling, and enables the switches to be used for providing value-added services (Egan, 1991). A company may have distinct skills in augmenting its lines with embedded software to handle the basic calling functions. Conversely, it may retain its more expensive switches for providing services of a more complex nature which also earn revenues at a higher rate. Similarly, among the telecommunications companies, because routines vary there can be differences in using the identical 5-ESS switch between two neighboring carriers, with consequent efficiency outcomes.

A historical example illustrates the social complexity ideas. In the early U.S. telecommunications industry several companies, using the same technology and resources, provided services. Other than Bell system companies several independent companies had equal market presence. The Bell system management understood the importance of interconnection in exploiting the technology. Under Theodore Vail the acquisition of many independent companies was carried out. Thereafter, the Bell system was able to implement a standard organization, based on the exploitation of then critical functional skills such as billing, engineering, and traffic.

Subsequently, articulating the universal service concept, Bell system managers were able to influence employees to interact throughout a vast organization in operating a telecommunications system which operated almost faultlessly for decades. As a result of the possession of unique coordination skills, as well as the exploitation of technology in a network context because the system was highly interconnected, Bell system managers were able to develop a seamless national telecommunications infrastructure in the United States, which the other independent telephone companies could not do (von Auw, 1983).

Examples from other industries

The ideas can also be illustrated using other examples. Take the investment function which involves activity interdependencies between various parties, with purchasers needing to transmit and receive information, technology and ideas from suppliers and other organizations. Airlines such as British Airways, KLM, Northwest Airlines and Singapore Airlines can serve as examples. These airlines possess the same types of aircraft. Pilots and cabin crew possess the same types of skills and capabilities. Ground-related and administrative activities are similar. Yet, coordination of interdependencies may differ, leading to performance variations.

Take fleet ownership where two broad

approaches are possible: purchase or leasing. One airline, having identified the possession via purchase of a high-quality fleet as a priority, may set up close liaison with manufacturers. In the process it can become a launch customer and interact closely in the design of aircraft. Aircraft can be customized to its detailed specifications during manufacture. Such activities have spillover consequences for crew training, which can be carried out in cooperation with the manufacturers, as well as integration of new aircraft into the fleet. Another airline may choose the leasing option. Close liaison with manufacturers is not set up. Maintenance of aircraft is also subcontracted to other airlines. Yet, the second airline may liaise closely with the first in crew training so that service standards are met. Conversely, a third airline interested in fleet upgradation may order aircraft for purchase but not coordinate extensively with the manufacturer. Uncoordinated aircraft acquisition can have consequences on crew training, may disrupt fleet composition, and affect maintenance. These factors can have a negative impact on service quality and on the airline's efficiency.

Consider the consulting industry in which the 'Big Six' accounting firms are key players. They utilize the same resources. The principal resource is human capital, and the supply comes from the major business schools' programs. Yet, in the industry Andersen Consulting has grown dramatically; it has also been able to expand during an industry downturn when other firms were retrenching (Ackenhusen, 1992). A key reason for Andersen Consulting's success is its skills in human capital development and deployment in consulting assignments. In developing human capital, training and promotion are coordinated over the career life cycle of individual consultants, across geographic units, and across functional disciplines. This permits development of homogeneous skills among human resources, assuring service consistency and client satisfaction. In deploying human capital, staffing is coordinated across assignments and geographic units, while training supports early on-the-job responsibility expectations of consultants. Though resources between the firms are similar and how Andersen Consulting undertakes coordination may be visible, these skills are imperfectly imitable by the other firms and provide for Andersen Consulting's superior performance.

Interfirm coordination skills between firms may turn out to be equally effective, leading to performance similarities. In the airlines case, British Airways, KLM and Singapore Airlines may each possess unique coordinating skills; these sets of skills may be equally effective, leading to superior performance compared to other airlines. Yet, at the intrafirm level these skills are invisible, difficult to substitute[6] and not easy to imitate. If measures denoting the possession of resources by firms, in this case firms in the telecommunications industry, can be used to ascertain patterns of resource utilization, then the variations in such patterns can arise due to differences in coordination skills between firms. By analyzing efficiency differences between the telecommunications firms, the subsequent empirical analysis attempts to demonstrate how researchers may gain insights into whether the possession of certain resources impacts performance; they may also gain insights into how much of the performance differences between firms arise due to causal ambiguity engendered by the possession of superior coordination skills.

USE OF DEA IN RESOURCE UTILIZATION ASSESSMENT

Description of DEA

Basic details

Data envelopment analysis takes into account observation-specific factors in the computation of a firm-level resource utilization measure. Charnes, Cooper, and Rhodes (1978) [CCR] develop, while Banker, Charnes, and Cooper (1984) [BCC] and Charnes *et al.* (1985) [CCGSS] extend the Farrell (1957) measure of efficiency

[6] This aspect may be true even for the various divisions within one specific firm. Hence, intrafirm transfer of coordination skills may be difficult. For example, Maitland (1983) details substantial productivity differences between two identical Goodyear plants in erstwhile West Germany and England, because of the way intraplant work procedures were coordinated at each plant. Thus, one reason why diversification efforts may fail is that the coordination skill-set assumed to be leveragable from one division to start a business in another may be imperfectly substitutable in the new division. Success in diversification efforts by exploiting economies of scope (Teece, 1980) then hinges on the relative transferability of the coordination skill-set from one business or division of a firm into another.

to a multiple output–input case using a fractional mathematical program, which is translated into a linear-programming formulation. See the Appendix for a general technical formulation and additional details.[7]

DEA helps ascertain firm-level differences in resource utilization. It is a technique that converts multiple input and output measures into a single measure of relative performance for each observation in a data set. The ratio of the weighted outputs to weighted inputs of each observation is maximized. This is a measure of performance as to how efficient each observation is in converting a set of inputs jointly and simultaneously into a set of outputs. Data required for computational purposes are an output vector $\mathbf{Y}_r = (y_{1j}, y_{2j}, \ldots y_{rj})$, of outputs $r = (1, 2, \ldots R)$, for observations $j = (1, 2, k \ldots N)$ and an input vector $\mathbf{X}_i = (x_{1i}, x_{2i}, \ldots x_{ij})$, of inputs $i = (1, 2, \ldots I)$, for each of the j observations. These can be obtained from firms' records or external sources.

The general DEA model is presented by the following formulation:

$$\text{Max: } e_{k,k} \tag{1}$$

subject to:

$$e_{j,k} \leq 1, \forall \text{j} \tag{2}$$

$$\mu_{r,k} \geq \in, \forall \text{r} \tag{3}$$

$$\nu_{i,k} \geq \in, \forall \text{i} \tag{4}$$

where:

(a) $e_{k,k}$ is a ratio measure of performance, an efficiency score, as to how efficient each kth firm-level observation is with regard to jointly and simultaneously converting a set of multiple inputs, or resources, $\mathbf{X}_i$ into a set of multiple outputs $\mathbf{Y}_r$;
(b) k is the index for the observation specifically being assessed or evaluated;
(c) $j = 1, 2 \ldots k \ldots N$ is the index for all the firm-year observations in the data set;
(d) $e_{j,k}$ is the relative efficiency of observation j, when observation k is evaluated;
(e) the j observations produce r outputs; $r = 1, \ldots R$ is the index for the outputs;
(f) the n observations consume i inputs; $i = 1, \ldots I$ is the index for the resource inputs;
(g) $\mu_{r,k}$, $\nu_{i,k}$ are the output and input weights associated with the evaluation of observation k;
(h) $\in$ is a very small positive nonzero quantity.

The optimization in (1) is repeated n times, once for each observation in the data set for which efficiency is to be evaluated; thus a separate evaluation of efficiency is carried out for each kth firm-level observation. Each time the optimization is carried out, data for all j observations form part of the constraint set, so that the observation is compared against all others in the data set; the constraint in (2) implies that the efficiency of any other observation in the constraint set cannot be greater than 1. Constraints (3) and (4) imply that there cannot be any negative inputs and outputs. The objective function values obtained partition the data set into two parts: one part consisting of efficient observations which determine an envelopment surface or frontier; the other part consisting of firms which are inefficient and for which $e_{k,k} < 1$.[8]

The weights, $\mu_{r,k}$ and $\nu_{i,k}$ in (g) above, are determined each time the optimization in (1) is carried out. Based on data, the DEA procedure takes each observation's idiosyncrasies into account in evaluating efficiency; the computation of weights is based on a determination of which input(s) a particular observation is adept at utilizing, or which output(s) it is adept at in generating. By assigning high weights to the input and output variables an observation is adept at in utilizing or generating, and low weights to the others, the algorithm maximizes the observed performance of each observation in light of its particular capabilities.

[7] In the economics literature, interest in the use of frontier production function techniques follows the appearance of work by Aigner and Chu (1968), Forsund and Hjalmarsson (1974) and Timmer (1971), among others.

[8] See Charnes *et al.* (1994) and Seiford and Thrall (1990) for detailed technical material, discussions of the various models feasible within a DEA framework, software availability and applications of DEA, as well as discussions of the extensions to performance analysis that have taken place within a DEA framework.

An illustration of the concepts

DEA concepts are illustrated using a simple example of four firms; A, B, C, and D, which use two inputs to produce one output. Each firm is characterized by the level of each input required to produce the output. If the consumption of each input is normalized relative to the level of output produced, the firms can be represented as in Figure 2. A firm which is efficient in one model is also efficient in the other; inefficient firms' efficiency scores may differ somewhat between these two approaches.

In Figure 2, A, B, and C are equally efficient firms but use different quantities of inputs 1 and 2 to produce the same level of output and appear on different segments of the frontier; D, however, is not an efficient firm. An observation such as D which is not efficient is evaluated against a hypothetical comparison unit (HCU) D* that is constructed as a convex combination of other efficient observations in the referent set for each observation. Thus, units A and B influence the construction of D* in differing proportions and form the referent set for D. Data in respect of the specific proportional influence that A and B have on D* are generated by the algorithm.

For managers of firm D, data on how much each member of the referent set, firms A and B, influence the construction of D* denotes firms similar to D in terms of resource utilization. These are the firms against which the strategies of D ought to be benchmarked. C is also efficient, but does not influence the construction of D*. Firms such as A, B, and C are efficient; therefore, the construction of an HCU is not relevant for these firms. Nevertheless, for each efficient firm the algorithm generates a list of other efficient firms similar to it in resource utilization. Such information can be used for strategic benchmarking purposes by managers of the efficient firms, so that standards for evaluating the future performance of already efficient firms are set.

Also, in the literature one concept of a strategic group is based on mobility barriers created by firms which possess strategically relevant resources (McGee and Thomas, 1986). Contemporary strategic group research has been criticized for its ad hoc nature (Barney and Hoskisson, 1989). The referent sets produced using the DEA framework generate a grouping of firms which is useful for analysis purposes and is based on firms' empirically observed resource-utilization capabilities (Day, Lewin, and Li, 1995). This attribute, in turn, is influenced by firms' resource mobilization and configuration strategies, rather than groups being derived on the basis of researcher-imposed criteria.

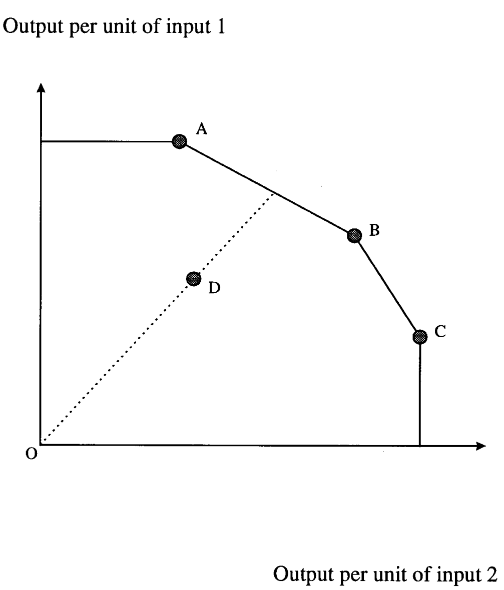

Figure 2. Efficient frontier for four firms with two inputs and a single output

What DEA involves

DEA involves the construction of a piecewise linear frontier. Given data, the algorithm identifies sets of firms based on production characteristics as defining one portion of this piecewise frontier. Each nonefficient firm belongs to one of these sets, and the efficient firms from each such set define the HCU for a nonefficient firm. The identification of sets is complex because the algorithm performs a nonlinear optimization where there are multiple output and input variables.[9] This optimization is performed as many times as there are numbers of observations in the data set. After all optimizations are complete, the algorithm groups together firms based on similarities in production correspondences. If different inputs and outputs are used for the same data set, different referent sets will emerge

[9] Contrast this with basic multiple regression analysis where there is a single linear optimization with one dependent variable but multiple independent variables.

because production correspondences between different variables are not the same.

For nonefficient firms, the algorithm reveals the precise quantity of each input that it should have consumed, if it were to be as efficient as its HCU. In other words, given the output produced, the inefficient observation could have consumed much less of the input in question without a loss in any of the outputs produced. The quantification of the overconsumption of different inputs can pinpoint the specific inputs in respect of which the firm's strategies for utilization ought to be reassessed (Leibenstein and Maital, 1992). This attribute permits firm-level strategic benchmarking.

The choice of a particular group of inputs and outputs to be evaluated in a DEA model implies that firms are being assessed as to how they utilize a particular skill set. Each set of inputs and outputs proxies for different skills that firms can possess. The choice of input mix and output mix represents a firm's strategies as to how that skill set is to be configured. The DEA resource utilization result denotes how well the skill set is deployed; this deployment is influenced by a firm's coordination abilities. For a given set of inputs and outputs, there will be differences in the DEA resource utilization scores as to how different firms exploit that skill set. Within a set of firms, different firms can choose to focus on developing and exploiting a particular skill set. Therefore, even for that group of firms DEA scores for two different sets of inputs and outputs need not be highly correlated.

Within the BCC and CCR models there are two orientations. In the first, the sum of weighted outputs is constrained to unity and the inputs needed are minimized. In the second, the sum of weighted inputs is constrained to unity and the outputs are maximized. An efficient firm will be efficient in both orientations. In the input-conserving orientation the focus is on a maximal movement towards the frontier by reducing inputs for an inefficient firm; in the output-augmenting orientation the focus is on a maximal movement towards the frontier by increasing outputs for an inefficient firm.

Differences in orientation lead to different referent set definition. This has implications for benchmarking by inefficient firms. Under the input-conserving algorithm one particular group of firms forms the referent set for the inefficient firm. Under the output-augmenting orientation another group of firms forms the referent set for the inefficient firm; however, the same firms that formed the input-conserving referent set may form the referent set as for the output-augmenting orientation but each firm's relative influence is now different.

Empricial analysis using cross-sectional data

Sample description

The use of DEA is illustrated by calculating three sets of resource utilization scores for 39 telecommunications operating firms in the United States for the year 1990, using the estimating approaches. In the United States the telecommunications industry consists of several sectors such as local and long-distance services. In the local sector, AT&T was the dominant monopoly supplier, but did comprise of 22 separate operating companies (BOCs). Other operating companies include those belonging to diverse groups such as GTE, United, Continental, and Central telephone systems, as well as independents such as Cincinnati Bell, Rochester Telephone, and Southern New England Telephone. These non-Bell (called non-RHC after 1984) companies provide telephone services to over 60 percent of the land area of the United States. There is a good deal of firm-level heterogeneity as a result of how the industry evolved.

The local operating companies in the sample account for over two-thirds of telephone activities in the United States; their total revenues for 1990 were at least $80 billion or over 95 percent of local operating company revenues. There are also specialized common carriers (SCCs), such as AT&T Communications, MCI, and Sprint which since 1984 are responsible for interstate and inter-LATA (local access and transport areas) long-distance calls. A LATA is a geographic area analogous to the old local exchanges. A LATA is a regional calling area that can embrace one or more contiguous exchange areas and transcends municipal, but not state, boundaries.

Local operating companies provide the primary telecommunications infrastructure. Recent legislation passed by the U.S. Congress recognizes the importance of this sector, and the sector has been fully opened up to competition. Historically, until the 1984 reorganization, the companies had the exclusive market for all calls, including in-state long-distance calls, within a state. Until now in-state, but inter-LATA, long-distance calls have been the responsibility of the SCCs, while local operating companies have had almost exclusive carriage rights for intra-LATA toll services. Operating companies could not participate in inter-LATA markets, a restriction removed through recent legislation. Thirty-nine key operating firms, of which 22 are erstwhile AT&T Bell Operating Companies and 17 are independent companies, are evaluated. This is almost the entire population of the key firms making up this sector.

DEA models estimated

For analyses, the BCC algorithm is used in its input-conserving and output-augmenting orientations to estimate three models. This BCC model is the most commonly used.

Model 1

Two outputs (r = 1, 2) are used. These are: (1) total number of local calls, and (2) total number of toll calls made using the firms' infrastructure. Three resource inputs are used (i = 1, 2, 3). These are: (1) total number of switches, (2) total number of access lines, and (3) total number of employees. This model captures skills in physical resource usage. In 1990, these 39 firms operated 14,181 telephone switches, 127 million telephone lines, and employed 528,282 persons. These resources are comparable between firms. The switches are obtained from a limited number of suppliers such as Alcatel, AT&T, or Northern Telecom which supply all the firms. The lines use either copper-wire or fiber-optics technology available to all the firms. There is some heterogeneity in human capital, but the employees belong to the same union: the Communication Workers of America.

The outputs in this model are ones over which the firms can have little control, because the volume of calls is a function of customer, territory, and institutional characteristics. Given levels of output firms can develop resource allocation, task identification, and interdependency managing procedures so that the inputs available are used efficiently. Coordination procedures help firms to optimize usage of resources in providing the outputs. For example, procedures may exist to simplify allocation of lines based on evolving traffic patterns and to ensure that the utilization of lines is maximized at any point in time. This will ensure higher efficiency of the lines infrastructure.

Model 2

Three outputs (r = 1, 2, 3) are used. These are: (1) local revenues, (2) toll revenues, and (3) other revenues. The resource inputs used in Model 1 are retained in Model 2. These are: (1) total number of switches, (2) total number of access lines, and (3) total number of employees. In 1990, these 39 firms earned $35.58 billion in local revenues, $13.28 billion in toll revenues and $32.03 billion in other revenues, which were access revenues, directory advertising revenues, and some miscellaneous items of revenue. The total revenues for the 39 companies in 1990 were $80 billion. This model proxies for the skills involved in using physical resources to generate revenues. These skills may vary between different firms. Given physical inputs, and allied physical outputs, some firms may be able to receive a higher rate of revenue per unit of output. This ability requires skills in coordinating activities which other firms may not possess.

The companies have relatively little control over the volume of calls made; but they can influence the rate at which revenues are earned. Though local call rates are set by regulatory authorities, there can be variations in skills within the firms in managing the regulatory interfaces, so that higher local calling rates are awarded to some firms. Additionally, companies can offer a range of services, such as automatic call-back, call-holding and voice mail which help to generate revenues with their given infrastructure. With respect to long-distance revenues, regulatory constraints are lesser and firms can undertake various pricing strategies to generate toll revenues. Access revenue rates are mandated by regulators, but a number of companies undertake directory advertising to boost their other revenues. Some firms can have considerable skills in boosting their nonregulated revenues.

Model 3

Two outputs (r = 1, 2) are used. These are: (1) local calls and (2) toll calls. The outputs are those used in Model 1. Four inputs are (1) plant-specific operational expenses, (2) nonplant-specific operational expenses, (3) customer operational expenses, and (4) corporate operations expenses. This model is similar to Model 1. The physical resources that firms possess have an attached price. Some firms can possess superior factor market-related skills and can acquire resources more efficiently or cheaply than others. This model can highlight that firms differ in the way they coordinate factor acquisition and the relative amounts paid by the different firms for the different inputs. If there are no differences in factor acquisition skills between firms, then the efficiency scores in Model 1 and Model 3 (the outputs are the same in both) would be roughly the same.[10]

Model 1, 2 and 3 analyses: Basic results

The correlations between the scores generated using the input-conserving orientation and the output-augmenting orientation are as follows: for Model 1 the r = 0.991, for Model 2 the r = 0.965 and for Model 3 the value for r = 0.990. Table 1 lists the scores attained by the 39 firms evaluated for Models 1, 2, and 3. There are a number of frontier-defining firms; 21 firms score 1, on a scale of 0 to 1, in Model 1, 17 firms attain a score of 1 when Model 2 is used, while 18 firms are efficient in Model 3.

The average scores for Models 1, 2, and 3 are similar, being 0.892, 0.898, and 0.862. The minimum score, say for Model 1 is 0.576 for New York Telephone, denotes that the efficiency of this firm is 57.6 percent that of the efficient firms scoring 1 in the sample. These scores give researchers and managers of each firm an indication of the relative strategic performance of the firms, and of skill differences. The correlation between Model 1 and Model 2 scores is low, r = 0.040. These models proxy for different skill sets. Correspondingly, the correlation between Model 1 and Model 3 scores is 0.699, while the correlation between Model 2 and Model 3 scores is −0.379.

The scores for Models 1 and 2 can be classified to permit comparative assessment of firm-level skills. The inputs and outputs in Model 1 are expressed in physical units. Model 2 factors in a price component for the output measures. Rather than output being considered as calls, revenues, which are number of calls multiplied by the price of calls, are taken as outputs. Table 2 contains the detailed classification of firms' scores for Models 1 and 2.

As Table 2 shows, 12 out of the 39 firms are equally efficient, scoring 1 in both Models 1 and 2, in deploying the skill sets implied by Models 1 and 2. Correspondingly, nine firms are efficient in Model 1 but not efficient in Model 2, while five of the firms turn out to be efficient in Model 2 but not efficient in Model 1. Thirteen of the firms do not score 1 in any of the models. For the managers of the firms concerned, these data give them a sense of where their relative competencies lie. For example, Illinois Bell's managers are made aware that they are efficient in utilizing physical resources, but not in generating revenues. Managers at GTE North are made aware that they are effective revenue generators, but at the cost of wasted physical resources.

Comparative analysis of results for Models 1 and 2 is useful. For Illinois Bell managers, if only Model 1 results form the basis for action, no actions will be deemed necessary because Illinois Bell is efficient. For GTE North managers, if only Model 2 results are to form the basis for action, no actions will be deemed necessary because GTE North Bell is efficient. Yet, in both firms, attention is required to be paid to other facets of resource acquisition, integration, and utilization if Illinois Bell and GTE North are to be efficient in both Models 1 and 2 like, say, GTE California or Pacific Bell.

Industry observers can take note that Illinois Bell, Michigan Bell, Ohio Bell and Wisconsin Bell are efficient with respect to Model 1, physical resource utilization. These are all Ameritech companies. Such data give insights into the physical productivity orientation of Ameritech group companies. Conversely, these companies do not score 1 in Model 2 and their revenue acquisition

[10] A fourth model which takes into account the separate expenses as inputs and revenues as outputs can also be estimated. Potentially, in a contestable market environment this model is very useful as both inputs and outputs are measured in dollar terms. Evaluation of this model, along with the three other models demonstrated in the article, is left for future research. As the telecommunications environment becomes more competitive, following the 1996 Telecommunications Act, use of contemporary data and comparative analyses of firms' performance using all four models will shed light on the firm-level idiosyncratic predilections that characterize the local exchange companies' behavior in a fully competitive environment.

Table 1. DEA-generated scores: Cross-sectional results for 1990

Firm's name	DEA score: Model 1	DEA score: Model 2	DEA score: Model 3	Firm's name	DEA score: Model 1	DEA score: Model 2	DEA score: Model 3
Bell Pennsylvania	0.868	0.772	0.931	Mountain States	0.768	0.785	0.878
Cincinnati Bell	1.000	1.000	1.000	New England Telephone	0.741	0.823	0.686
Continental California	1.000	1.000	0.638	New Jersey Bell	1.000	1.000	1.000
Carolina Telephone	0.719	0.703	0.884	Nevada Bell	1.000	1.000	1.000
Central Telephone	0.910	0.760	1.000	Northwestern Bell	0.750	0.760	0.974
Chesapeake & Potomac	1.000	1.000	1.000	New York Telephone	0.576	1.000	0.443
C&P Maryland	0.951	0.838	0.838	Ohio Bell	1.000	0.833	1.000
C&P Virginia	0.912	0.846	0.846	Pacific Bell	1.000	1.000	1.000
C&P West Virginia	0.831	1.000	1.000	Pacific Northwest Bell	0.764	0.805	0.905
Diamond State	1.000	1.000	1.000	Rochester Telephone	1.000	0.869	1.000
GTE California	1.000	1.000	0.527	South Central Bell	1.000	0.917	1.000
GTE Florida	0.581	0.930	0.577	SNET	1.000	0.979	0.877
GTE Hawaii	1.000	1.000	0.759	Southern Bell	1.000	1.000	1.000
GTE North	0.739	1.000	0.776	Southwestern Bell	1.000	1.000	1.000
GTE Northwest	0.624	1.000	0.516	United Indiana	1.000	1.000	1.000
GTE South	0.685	0.994	0.600	United Ohio	0.769	0.887	0.696
GTE Southwest	0.603	1.000	0.447	United Pennsylvania	1.000	0.671	1.000
Illinois Bell	1.000	0.814	1.000	United Intermountain	1.000	0.919	1.000
Indiana Bell	0.928	0.751	0.931	Wisconsin Bell	1.000	0.774	1.000
Michigan Bell	1.000	0.751	1.000				

Table 2. Firm-level comparison between Model 1 and Model 2 of relative capabilities for 1990 observations

Criterion for comparing relative capabilities	Firm name
Efficient in utilizing physical resources in generating calls as well as in generating revenues (Model 1 score [=1] = Model 2 score [=1])	Cincinnati Bell; Continental California; Chesapeake & Potomac; Diamond State; GTE California; GTE Hawaii; New Jersey Bell; Nevada Bell; Pacific Bell, Southern Bell; Southwestern Bell; United Indiana
Efficient in utilizing physical resources in generating calls but not in generating revenues (Model 1 Score [=1] > Model 2 Score [<1])	Illinois Bell; Michigan Bell; Ohio Bell; Rochester Telephone; South Central Bell; SNET; United Pennsylvania; United Intermountain; Wisconsin Bell
Not efficient in utilizing physical resources in generating calls but efficient in generating revenues (Model 1 Score [<1] < Model 2 Score [=1])	C&P West Virginia; GTE North; GTE Northwest; GTE Southwest; New York Telephone
Not efficient in either utilizing physical resources in generating calls or in generating revenues, but resource utilization in generating calls is better than revenue generation (Model 1 Score [<1] > Model 2 Score [<1])	Bell Pennsylvania; Carolina Telephone; Central Telephone; C&P Maryland; C&P Virginia; Indiana Bell
Not efficient in either utilizing physical resources in generating calls or in generating revenues, but revenue generation is better than resource utilization in generating calls (Model 1 Score [<1] < Model 2 Score [<1])	GTE Florida; GTE South; Mountain States; New England Telephone; Northwestern Bell; Pacific Northwest Bell; United Ohio

skills are superior to that of, say, New York Telephone which is efficient in Model 2 but not in Model 1. New York Telephone has a large base of installed assets with which to generate calls. Its physical resource utilization is comparatively low. However, its score of 1 on Model 2 suggests that it generates a high rate of revenue per call compared to a number of the other firms.

Detailed firm-by-firm comparison is not carried out for Models 1 and 3. The overall results are, however, interesting. The correlation between these models is 0.699. The outputs in both models are now the same (local and toll calls); however, the inputs are different. Now, the inputs in Model 3 are not in physical units but have prices factored. Factor market strategies and skills can lead to the payment of lower acquisition prices for resources. The relatively high correlation suggests that the firms' skill sets with respect to physical resource utilization as well as in resource utilization once factor prices are taken into account are similar. As Table 2 shows, however, there are only nine firms of the 39 studied which are efficient in all three models. These firms can set the standards against which the other firms in this sector of the industry may benchmark themselves.

Referent set analysis

For each firm, those which are efficient (score = 1) as well those firms which are inefficient (score < 1), the algorithms generate a list of the other firms in the sample that form the referent set. For the inefficient firms, the algorithm generates a statistic which denotes precisely how much each referent set member influences the construction of the HCU. The proportion that each referent set member influences the HCU construction varies between the input-conserving and the output-augmenting orientations. Given space limitations, the insights that are drawn from the information contained in the table is illustrated by only using Model 1 data for two firms for exposition purposes. These firms are GTE North and Illinois Bell.

Table 3 gives details of the referent sets for Model 1. GTE North is inefficient and scores 0.7394; it is an independent operating company not belonging to one of the RHCs. It carries out activities in 11 states in the Midwest and upper-Midwest of the United States. In its referent set the efficient comparator firms are Michigan Bell, South Central Bell, and United Intermountain. Michigan Bell, because of demographic and other similarities in the area of its territorial coverage with GTE North, influences the construction of the HCU for GTE North to the extent of 38.6 percent. While South Central Bell does not operate in similar territorial jurisdictions, it is also a large multistate operator; therefore, it has some influence, 10.6 percent, in the construction of the HCU for GTE North.

United Intermountain has the most influence, 50.8 percent, in the construction of GTE North's HCU under the input-conserving orientation while the highest percentage is 52.6 under the output-augmenting orientation and now the firm is Michigan Bell. United Intermountain is the relevant firm for GTE North to benchmark its physical resource exploitation strategies against. United Intermountain is an independent company of similar size and territorial scope. As an independent operator in a territory where the bigger Bell companies operate, it faces constraints similar to those faced by other independent companies and different from those faced by the Bell companies. Therefore, its physical resource utilization can be similar to that of GTE North. Detailed analysis of United Intermountain's strategies can give GTE North's management a sense of where their failings are and how their specific strategies have led to inefficiencies. Conversely, GTE North operates in the same broad geographic area as Michigan Bell and faces similar output generation and regulatory constraints. Thus, Michigan Bell is a useful benchmark against which to assess output augmentation schemes.

Illinois Bell is an efficient company, scoring 1. It is a single-state operating company owned by Ameritech, an RHC, and operates in the Midwest, in a state where there is a large population, heterogeneity in the rural–urban mix as well as the presence of a large urban conurbation: Chicago. Its referent firms, under the input-conserving orientation, are Michigan Bell, Ohio Bell, and Southern Bell. Michigan Bell and Ohio Bell are also single-state firms operating in similar circumstances, and their strategic predilections closely resemble that of Illinois Bell since they are owned by the same parent. Southern Bell operates in a territory that has similar rural–urban heterogeneity to Illinois Bell and is also a referent set firm for Illinois Bell. Strategic benchmarking against these firms will be of use to Illinois Bell's

Table 3. Referent set analysis: 1990 observations

Firm's name	Efficient or not	Referent firms	Orientation	Proportion influenced
GTE North	NO	Michigan Bell	Input-conserving	0.386
		South Central Bell		0.106
		United Intermountain		0.508
GTE North	NO	Michigan Bell	Output-augmenting	0.526
		South Central Bell		0.154
		United Intermountain		0.319
Illinois Bell	YES	Michigan Bell	Input-conserving	
		Ohio Bell		
		Southern Bell		
Illinois Bell	YES	Michigan Bell	Output-augmenting	
		New Jersey Bell		
		Ohio Bell		

managers. In the output-augmenting orientation the referent set firms are now Michigan Bell, New Jersey Bell, and Ohio Bell.

Excess input analysis

Table 4 provide a quantification of the excess amount of each resource that an inefficient firm has consumed relative to the total quantity of that resource actually consumed. Of the total quantity used the proportion that is wasteful use is measured. The input-conserving DEA Model 1 algorithm generates the input quantity of each resource an inefficient firm ought to have consumed to produce the same levels of outputs if it were efficient. The difference between actual and efficient consumption of each resource is the excess input; the relative proportion of excess

Table 4. Analysis of input slack using Model 1 results: Cross-sectional data for 1990

Firm's name	Switches	Lines	Employees
Bell Pennsylvania	13.171	13.170	13.168
Carolina Telephone	28.052	28.053	42.151
Central Telephone	9.006	9.006	9.006
C&P Maryland	4.894	4.894	4.894
C&P Virginia	8.771	8.771	8.771
C&P West Virginia	16.858	16.858	16.858
GTE Florida	41.934	41.934	45.795
GTE North	75.292	26.064	44.403
GTE Northwest	32.596	32.596	43.128
GTE South	44.426	31.487	49.913
GTE Southwest	54.006	39.086	55.117
Indiana Bell	7.185	7.185	7.185
Mountain States	25.230	23.241	23.240
New England Telephone	29.992	25.900	33.733
Northwestern Bell	35.759	25.003	25.000
New York Telephone	42.426	42.426	50.313
Pacific Northwest Bell	23.626	23.626	23.626
United Ohio	23.114	23.114	37.196

input pinpoints the specific resources for which utilization strategies have to be reconsidered in light of the analysis.

In general, a firm's excess resources consumption as a proportion of the total actual resources used broadly mimics its overall efficiency score. In other words, if a firm's managerial efficiency score, say that of Bell Pennsylvania, is 0.8683, its proportion of excess to actual consumption will be 0.1317, or 13.17 percent. For some firms the consumption of excess resources may be in equal proportions for all the resources. There are some firms, among others Bell Pennsylvania, Indiana Bell and Pacific Northwest Bell, for which this is the case, as Table 4 shows. Of relevance is the analysis of firms in which there are differences in the proportion of the excess to actual consumption for each of the different resources, since it has been stated earlier in the paper that there can be variations within firms in using lines vs. switches or between using physical assets and human assets.

A comparison of the proportion of the excess to actual consumption for switches and lines shows that of the 18 inefficient firms, five firms, GTE North, GTE South, GTE Southwest, Mountain States, and Northwestern Bell, are more inefficient in utilizing their switching resources relative to their resources of lines. For these firms, reassessment of strategies for the deployment and utilization of switches becomes important, especially with the technological developments that are continuously taking place. In Table 2, the main comparator firm for GTE North is United Intermountain. A review of United Intermountain's strategies for the deployment and utilization of switches is likely to be of benefit in the strategic reassessment exercise that GTE North carries out.

A comparison of the proportion of the excess to actual consumption for line and employees shows that nine of the 18 inefficient firms are worse off in managing their employees relative to their infrastructure of lines; in each situation the proportion of the excess to actual consumption for employees is greater than that for lines. These data call into question the resource configuration strategies that the firms have adopted in putting together an appropriate mix of physical and human capital. For example, in GTE Southwest and New York Telephone over half the employees deployed are excess to current output needs; these employees can be retrained or deployed in other activities.

Segmentation by overall ownership category

Segmentation of firms controls for factors other than intrafirm skills which may affect resource utilization. The 39 firms are segmented into two broad ownership categories: the Baby Bells (the seven Regional Holding Companies which own 22 of the Bell operating companies) and the independent companies. There is logic for such segmentation since the Baby Bells have a stronger urban as well as business sector presence. They can gain from network densities as well as customer concentration. Conversely, the independent companies' area of coverage is more than half of the continental United States. Yet, the revenues of the Baby Bells are five times greater than that of the independent companies. The independent companies operate in far-flung territories where customer density is much lower than that in the territories of the Baby Bells. The efficiency scores for each category of firms, the Baby Bells, or the independent companies are given in Table 5.

As Table 5 shows, the efficiency of the Baby Bells, as captured by the physical resources utilization scores of Model 1, is superior to that of the independent companies. Density effects are exogenous factors which can affect the efficiency of telephone companies, and the Baby Bells do better in managing their physical assets relative to the independent companies. In Model 2, when types of revenues are taken as the output variables, the Baby Bells score higher on average than the independents. The independents, thus, do not seem to possess skills in acquiring revenues relative to the Baby Bells; these firms may, perhaps, enjoy favorable regulatory treatment relative to the Baby Bells because the latter firms are more dominant; however, their operating territories are such that it is not feasible for the independent companies to generate relatively higher unit price realizations. The comparative results with respect to Model 3 are similar to that for Model 1.

Dynamic performance analysis

DEA permits dynamic resource utilization analysis. This is carried out for the 39 firms for six periods: 1975, 1978, 1981, 1984, 1987, and 1990.

Table 5. Average scores for different models between groups of firms: 1990 data

	Model 1: Input-conserving	Model 1: Output-augmenting	Model 2: Input-conserving	Model 2: Output-augmenting	Model 3: Input-conserving	Model 3: Output-augmenting
Baby Bells	0.935	0.937	0.975	0.979	0.935	0.938
Independents	0.912	0.919	0.957	0.941	0.872	0.887

During this time major environmental changes took place; some implications of environmental change can be assessed. The gradual opening up of markets induces firms to improve resource utilization (Leibenstein, 1987) with the onset of competitive forces destroying monopoly rents and replacing these with efficiency rents (Demsetz, 1989). Such factors can alter resource accumulation strategies within firms, with changes taking place in capabilities, impacting on how resources are used. Hence, the performance of firms changes noticeably over time. In an evolving competitive environment a greater volume of information emerges as firms undertake varied strategic experiments to compete and to grow (Hayek, 1945).[11] As individual firms process these data, interfirm variations in resource utilization are likely to increase since the same set of information may be processed and acted upon differently by different firms which possess widely varying information-processing predilections.[12]

1975 is chosen as a year when there was no competition in the industry. Between 1978 and 1981 technology-driven transition occurred because of the diffusion of electronic switching. The period 1981–84 is one of political transition, when a number of competition-enhancing policy events took place. The last phase, 1984–90, is one of consolidation and transition to a competitive environment, propelled by the Reagan administration's pro-competition policies. After 1984, transformation also took place within the erstwhile AT&T-owned operating companies. With the divestiture of operating companies into seven distinct units, different cultural milieus were substituted for the old AT&T culture. The Baby Bells were transformed in a short period of time to competitive and nonbureaucratic organizations (Tunstall, 1984). Changes were also instituted by the other independent operating company groups, who found some open markets into which they could expand their operations. Conversely, their own prior-protected turfs were being thrown open to competitors. As a result, in the post-1984 period significant changes are likely to have taken place in how business activities were coordinated within the several operating companies.

The dynamic performance analysis is carried out using the Model 1 inputs and outputs. Table 6(a) lists descriptive statistics in respect of the Model 1 scores over time, while Table 6(b) shows the results of a statistical test evaluating significance timewise differences in these scores.

Within each time period there is substantial variation in the scores, revealing heterogeneity among the firms. The standard deviation of the scores is 0.148 in 1975 and in 1990 is 0.162. The coefficient of variation is 30.87 percent in 1975, but reduces to 19 percent in 1990, primarily because the mean score has risen, and not because the standard deviation has declined. By 1990 the coefficient of variation is again quite substantial, and differences in firms' abilities to utilize resources exist. The mean score for all the 39 firms rises from 0.479 in 1975 to 0.854 in 1990, showing that over time the firms have improved their abilities to extract more outputs with the various resources at their disposal.

[11] Conversely, the amount of information available through a process of diffusion to firms in regulated or controlled environments can be negligible or nonexistent since there are limited opportunities to undertake strategic experiments.

[12] Resource utilization problems can be considered as fundamentally dynamic. Hayek (1945) and Barnard (1968) had argued that a concern of firms was continuous adaptation to a fluctuating environment. Evolutionary dynamics can be driven by external shocks as well as internal firm-level forces. Hayek and Barnard were building on the work of Schumpeter (1934), who was concerned with how exogenous forces affected endogenous behavior. Schumpeter's seminal insights are in the explanation of how the macro-disequilibrium altered existing micro-arrangements, thus leading to fundamental changes in firms' activities and conditions (Dahmen, 1984). Schumpeter was equally concerned with endogenous innovations occurring as a consequence of entrepreneurs' vision.

Table 6(a). Descriptive statistics for the resource utilization measure (using Model 1 inputs and outputs) over time

Items	1975	1978	1981	1984	1987	1990
Mean score	0.479	0.482	0.499	0.814	0.855	0.854
Standard deviation	0.148	0.116	0.101	0.125	0.129	0.162
Maximum score	0.976	0.833	0.786	1.000	1.000	1.000
Minimum score	0.343	0.360	0.388	0.537	0.525	0.538
Interquartile deviation	0.169	0.126	0.102	0.203	0.244	0.270

Table 6(b). Statistical test results for differences in scores over time

	Difference in average score between 1975 and 1978	Difference in average score between 1978 and 1981	Difference in average score between 1981 and 1984	Difference in average score between 1984 and 1987	Difference in average score between 1987 and 1990
Test statistic	1.791	3.181	5.442	3.572	0.746
p-value	(0.073)	(0.002)	(0.000)	(0.000)	(0.456)

Table 6(c). Results of regression analyses

	Regression 1	Regression 2	Regression 3
Constant	0.332	0.630	0.333
Time	0.095		0.095
(*t*-statistic)	(16.42)		(15.87)
Volume growth		3.2E+7	−2.2E+8
(*t*-statistic)		(2.83)	(0.27)
R^2	0.537	0.038	0.538

Table 6(b) reports the results of a statistical test performed on the DEA scores. Period-to-period variations in scores for the sample of 39 firms are tested for significance using a nonparametric test proposed by Wilcoxon (1945). The Wilcoxon test is a nonparametric test comparing the means of two variables. The test evaluates the hypothesis that the resource utilization score for an earlier year, say 1975, is less than that of the later year, say 1978. In other words, the score for 1978 is statistically different, and greater, than the score for 1975. The Wilcoxon test is a matched-pairs test to test the difference between two paired groups. When a set of observations is evaluated as to whether the means of two groups are equal, this is the most powerful nonparametric procedure available.

Table 6 shows that between 1975 and 1987 firms have improved their resource utilization in every period succeeding the previous one, except between 1987 and 1990. 1978 is a year when some market entry was permitted, and new switching technology became available. In 1981 the legislative–judicial processes, leading to changes in the industry, commenced. The behavior of firms since then has been propelled by the need to operate in markets where competitive forces were unleashed, even though in practice the actual divestiture did not take place until 1984. The period-to-period score changes between 1981 and 1984, and 1984 and 1987, have the highest *p*-values. By 1990, industry changes had been in place for 6 years. Table 6 also shows that by 1990 idiosyncrasies in resource utilization among the firms are visible, as the higher standard and interquartile deviation values imply.

Two initial implications follow from the results of the dynamic performance analysis carried out. First, the increase in average scores is consistent with expectations that the opening up of markets induces firms to improve resource utilization and is consistent with other evidence (Crandall, 1991) for the telecommunications industry. Second, given the concept of uncertain imitability (Barney, 1991; Lippman and Rumelt, 1982), the increase in the interquartile deviation values between 1981 and 1990 indicates increasingly greater variation in firms' behavior.

With changes taking place in the firms' regulatory environment, there is increasing ambiguity involved in operating in a competitive scenario where options available to firms increase substantially. Firms experiment more on strategic and operational matters, since the gains from such experiments are unlikely to be subject to regulatory limits. As a result, greater information flow takes place between firms, increasing the variety of strategic choices feasible. This augmented information flow reduces the imitability of strategies, once feasible in a regulated environment where limited strategic options were available to firms and there were limited information sets among the firms to make imitative choices from. Performance variations, thus, become apparent as the firms adjust to different notions of operating within an evolving competitive scenario.

One reason, however, why efficiency can increase over time is simply volume growth. Such volume growth can help firms exploit economies of scale and become efficient. Whether the observed efficiency growth is a function of volume growth or arises because of other environmental or firm-level factors, changes can be assessed. The efficiency scores for Model 1 are regressed on a time-trend variable as well as a variable capturing volume growth, the variable total costs being a proxy for volume. The total costs variable is highly correlated with other variables capturing volume growth such as total calls, total revenues or total lines; these have, however, been used in the DEA computations. Interestingly, the correlation between the time-trend variable and the total costs variable is only 0.265.

Table 6(c) shows the regression results. When efficiency is regressed on time alone the coefficient is statistically significant, as regression 1 shows. When efficiency is regressed on the volume growth variable alone the coefficient is significant, as shown by regression 2. When the variables are jointly included in regression 3 the impact of volume growth is washed out while the coefficient for time remains significant. These dynamic efficiency increases support the notion that factors other than volume growth are influencing firms to improve their performance, and can be shifts in environmental conditions or factors within the firms themselves. Further analysis is necessary to understand the sources of dynamic efficiency increases.

CONCLUDING REMARKS

The assessment of resource utilization is important for future research in the resource-based approach to the firm. Firms may have skills in accumulating and organizing resources; but these are irrelevant if the resources are not utilized efficiently. Literature in the resource-based view has lightly dealt with resource utilization issues. Possibly, the number of reasons leading to interfirm heterogeneity may make efficiency an inadequate explanator of performance. Additionally, while bounded rationality (Simon, 1976) is an accepted theoretical assumption, the literature might have assumed that even somewhat rational agents try to use resources in as optimal a manner as possible.

Analysis of resource utilization ought to be a major item on the agenda of researchers in the resource-based paradigm. First, the issue of firm-level efficiency is of importance because how well resources are used determines firms' abilities to grow. The examples of South Korean firms which are global leaders because of their efficiency are well documented (Amsden, 1989); Chandler (1990) also demonstrates how attaining functional efficiencies led to the growth of U.S. firms in the 19th and early 20th centuries. Second, *x*-inefficiency is an empirically observed phenomenon (Leibenstein, 1987). Even if they are able to, firms may not utilize resources to the best of their ability. Thus, empirical analysis helps reveal firms' abilities or shortcomings.

Given the need to address resource utilization issues within the resource-based paradigm, the paper specifies theoretically why some firms might be better at utilizing resources than others. The DEA procedure is used to illustrate how differences in resource utilization between firms can be empirically ascertained. The deployment of this procedure is fundamental to the resource-based approach, since performance is measured in resource terms. A limitation is data sensitivity.

Therefore, application is suited to the analysis of firms consuming similar resources. Examples of some contexts within which DEA can be applied are: automobile manufacturing, banking, consulting, department stores, electrical machinery manufacturing, furniture retailing, hotels, garbage collection and insurance broking. In applications, attention has to be paid to the data that are to be used.

DEA is applied to illustrate patterns of resource utilization for local operating companies in the U.S. telecommunications industry. DEA generates firm-specific parameters of resource utilization. These data are useful for managers and researchers alike. The empirical analyses reveal variations in skills between the telecommunications firms. Though these firms use comparable resources in a similar industry, the process by which resources are coordinated within firms can lead to efficiency differences. For each firm, a list of the other firms making up its referent set is generated; these data are useful for strategic benchmarking. For inefficient firms, information on the excess quantity of each input consumed produced pinpoint areas needing managerial attention.

As Chandler (1990) has also argued, change in dynamic patterns of resource acquisition and utilization is a major reason why some firms forge ahead and grow while others are unable to do so. Additionally, recursiveness is an important characteristic. Following the initial acquisition of resources, these are configured into skill sets. But, once skill sets are developed, over time the strategies for resource acquisition continuously change, leading to changes in the mix of resources that firms possess. Similarly, there are specific skill sets which enable firms to transform resources into outputs. Feedback as to the way resources are transformed inculcates learning and leads to changes in the strategies required for conversion. Such a process may lead to changes in the strategies required for transformation and in the resource acquisition strategies now needed for the changed conversion skills.

The empirical illustration showed that there were significant increases in efficiency of the firms evaluated, but there were still substantial variations in efficiency. Detailed case-by-case analysis of changes in resource acquisition and utilization strategies between firms can also reveal what factors make some firms fall behind in their efficiency over time, and what factors engender forging ahead by other firms. Such analysis can shed light on the dynamics of industrial growth, which is spurred by firms' efficiencies, at a micro-level of analysis.

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APPENDIX: DEA

Features of DEA

There are a number of features of DEA which provide advantages for empirical research; there are also limiting conditions to be taken into account.

1. DEA handles multiple outputs and inputs simultaneously and deals with the use of joint inputs to produce joint outputs. Regression-based techniques handle only single-output estimation.

2. No assumptions about functional form other than convexity and piecewise linearity are made. This property is useful for the resource-based approach since functional relations between various inputs and outputs are often difficult to define, given causal ambiguity.

3. DEA makes no assumptions as to the technology used by firms. To assess how technological characteristics affect firms' resource utilization, in a second-stage analysis a variable capturing the nature of technology has to be factored in as a regressor in a model where the dependent variable is the DEA resource utilization measure.

4. The DEA algorithms generate coefficients that vary by firm. In a resource-based framework, the assumption is that of a heterogeneous variable-coefficients resource-conversion process, because in spite of two firms having exactly the same inputs, blueprints and codified rules with respect to the use of inputs, the end result observed is likely to be dissimilar even though only marginally.

5. DEA is oriented to frontiers estimation rather than estimation of central tendencies. DEA optimizes for each individual observation. Regression approaches are averaging techniques which proceed via a single optimization to arrive at a single parameter across all observations.

6. The use of DEA is limited by the data used. DEA is an extremal methodology and outliers supplied to generate the frontier can bias the results. Data on inputs and outputs among observations should be comparable. Depending on the level of detail for inputs and outputs used in the computations, different firms may be efficient on different dimensions of input use; therefore, input and output data have to be carefully selected based on theoretical and

practical considerations and consistently measured for all the observations.[13]

7. DEA results are applicable with respect to the firms for which data have been used in generating the results. Also, the frontier firms identified based on the analysis of one data set may not necessarily be operating at the theoretically attainable frontier. Also, data set design can be static or dynamic. All *n* observations can be taken for a particular year; thus, optimization for the *k*th firm is done with respect to its cohorts for that year only. Information for several years can be used to form a panel data set. An evaluation of the efficiency characteristics for each of the *j* observations is carried out with respect to observations belonging to the same year as the compared observation, and with respect to observations belonging to different years.
8. The CCR measure of efficiency consists of managerial efficiency and scale efficiency components. Banker *et al*. (1984) decompose the CCR measure into managerial efficiency and scale efficiency components. This is useful for research because firms' returns to scale characteristics are allowed to vary, which is in consonance with empirical realities.

Technical issues

Assume that there are *j* observations or decision-making units (DMUs), each consuming *i* different inputs to produce *r* different outputs. Defining

$$\max(\mu,\nu) = \sum_{r=1}^{R} \mu_r Y_{rk} \Big/ \sum_{i=1}^{I} \nu_i X_{ik} \qquad (5)$$

yields the basic DEA ratio form model, where the ratio of weighted outputs to weighted inputs is maximized; k (in a set of $j = 1, 2, \ldots k \ldots n$ DMUs) is the DMU being evaluated, $e_{k,k}$ is the efficiency measure for each observation, as in (1), Y_{rk} is the set (vector) of outputs produced by the kth observation with X_{ik} being the set (vector) of inputs; μ_r and ν_i are the weights obtained from the data and are not known *a priori*. Instead, they are calculated (in a manner similar to the way coefficients are calculated in a regression formulation) as values to be assigned to each input and output in order to maximize the efficiency score, $e_{k,k}$ of the observation being evaluated. The solution sought is the set of μ_r and ν_i values that will give the DMU being rated the highest efficiency ratio. The ratio form has a strong intuitive appeal because the efficiency measure is expressed as a ratio of a set of multiple outputs that an observation produces using a set of multiple inputs, and is an extension of the traditional single output–input ratio model.

The model in (5) is a fractional program difficult to solve. Charnes *et al*. (1978) show that using the procedure shown in Charnes and Cooper (1962) the model in (5) can be converted into a linear program which can be solved using less complex methods. Using data given in Table A1, a small numerical example is given as to the general principles of how DEA works. This simple numerical example uses the variable returns to scale algorithm developed by Charnes *et al*. (1985) [CCGSS] and is adapted from Charnes *et al*, (1994) [CCLS], in which further details may be found. Data for seven DMUs are given; only a single output and single input case is demon-

Table A1. Basic input and output data

Unit	Input X	Output Y
DMU or observation 1	2.00	2.00
DMU or observation 2	3.00	5.00
DMU or observation 3	6.00	7.00
DMU or observation 4	9.00	8.00
DMU or observation 5	5.00	3.00
DMU or observation 6	4.00	1.00
DMU or observation 7	10.00	7.00

[13] The literature on DEA is now large; Seiford (1996) lists a number of references. Only a few examples of inputs and outputs used can be given. In a study of Air Force property maintenance units Bowlin (1987) uses as inputs: supply costs, available direct labor hours, and available passenger-carrying vehicles; and as outputs: completed work orders, completed job orders, completed recurring work actions, and delinquent job orders. In a study of fast-food restaurants Banker and Morey (1986) use as inputs: expenditures on supplies and materials, expenditures on labor, age of store, and advertising expenditures; and as outputs: breakfast, lunch, and dinner sales. Though variables such as age can influence resource usage, such variables are secondary firm-characteristic variables. For estimating resource utilization differences between firms, analysts should include primary input variables which can be defined and measured according to the classification suggested within the resource-based approach. Managers can have the ability to vary the way in which such variables are combined to produce outputs; using such variables gives specific ideas of managerial efficiency. Conversely, a variable such as a unit's or a firm's age has to be taken as given by managers.

strated as it is not feasible to graphically show more than two dimensions.

The primal linear programming problem can be expressed as

$$\min\ (\lambda, s^+, s^-) \text{ where } z_k = -\vec{1}s^+ - ls^- \quad (6)$$

$$s.t.\ Y\lambda - s^+ = Y_k \quad (7)$$

$$-X\lambda - s^- = -X_k \quad (8)$$

$$\vec{1}\lambda = 1 \quad (9)$$

$$\lambda, s^+, s^- \geq 0 \quad (10)$$

The linear programming problem in (6) has a dual form which is expressed as

$$\max\ (\mu, \nu, u_k) \text{ where } w_k = \mu^T Y_k - \nu^T X_k + u_k \quad (11)$$

$$s.t.\ \mu^T Y - \nu^T X + u_k \vec{1} \leq 0 \quad (12)$$

$$-\mu^T \leq -\vec{1} \quad (13)$$

$$-\nu^T \leq -\vec{1} \quad (14)$$

The primal and the dual problems can both be solved using linear programming algorithms, with the optimal objective function value z^*_k (in 6) = w^*_k (in 11) = 0 signifying an efficient DMU. A DMU is efficient iff $z^*_k = w^*_k = 0$ (with * signifying optimal value). X, Y, X_k and Y_k are the observed input and output values for the DMUs and are constant. The variable sets for the linear programs are $\{\lambda, s^+, s^-\}$ and $\{\mu, \nu, u_k\}$ respectively; s^{+*} and s^{-*} are the slack vectors, λ and u_k are scale parameters while 1 is a vector of ones. The linear programming problems are solved n times, once for each DMU, with $(X_k, Y_k) = (X_j, Y_j)$ for $j = 1, \ldots n$. The objective function values partition the set of DMUs into two subsets; those observations for which $z^*_k = w^*_k = 0$ are efficient and determine the envelopment surface, while the other observations are inefficient and lie beneath the surface.

Table A2 reports the results obtained from both the primal (a) and dual (b) linear programs using the data that are given in Table A1. Units 1, 2, 3, and 4 are efficient, while units 5, 6, and 7 are inefficient with objective function values $w^*_5 = z^*_5 = -4$, $w^*_6 = z^*_6 = -5$ and $w^*_7 = x^*_7 = -4$. DMUs 1–4 define the efficiency frontier, while DMUs 5, 6, and 7 are inefficient.

Table A2(a). Results for the primal linear program problem

Unit	z^*_j	s^+	s^-	λ
DMU or observation 1	0	0	0	1
DMU or observation 2	0	0	0	1
DMU or observation 3	0	0	0	1
DMU or observation 4	0	0	0	1
DMU or observation 5	–4	2	2	1
DMU or observation 6	–5	4	1	1
DMU or observation 7	–4	0	4	1

Table A2(b). Results for the dual linear program problem

Unit	w^*_j	μ	ν	u_k
DMU or observation 1	0	1	3	4
DMU or observation 2	0	1	1	–2
DMU or observation 3	0	3/2	1	–9/2
DMU or observation 4	0	3	1	–15
DMU or observation 5	–4	1	1	–2
DMU or observation 6	–5	1	1	–2
DMU or observation 7	–4	3/2	1	–9/2

Associated with each inefficient DMU_j (X_j, Y_j) is an optimal comparison point on the envelopment surface. Optimal values for the slack variables obtained from solving the primal problem measure the *distance* from (X_j, Y_j) to this optimal point. As CCGSS and CCLS discuss, the model selects the point on the envelopment surface which maximizes the *distance* from the inefficient unit to the efficient point on the envelopment surface in a *northwesterly* direction. Specifically, for a DMU_k the primal problem picks the most extreme of all convex combinations of DMUs with output levels, $Y\lambda \geq Y_k$ and input levels $X\lambda \leq X_k$. Inputs have to be conserved and outputs augmented by an inefficient firm if it is to be as efficient as the optimal comparison point on the envelopment surface.

Thus, for DMU_5 where ($X_5 = 5$ and $Y_5 = 3$) this furthermost point with non-negative slacks occurs at DMU_2 (where $X_2 = 3$ and $Y_2 = 5$) with the *distance* of 4, computed as a nonzero input slack (since $X_5 > X_2$) of $5 - 3 = 2$ and a nonzero output slack (since $Y_2 > Y_5$) of $5 - 3 = 2$. Thus, if DMU_5 has to be efficient it has to conserve 2 units of input X and augment output Y by 2 units.

Similarly, for DMU_6 (where $X_6 = 4$ and $Y_6 =$

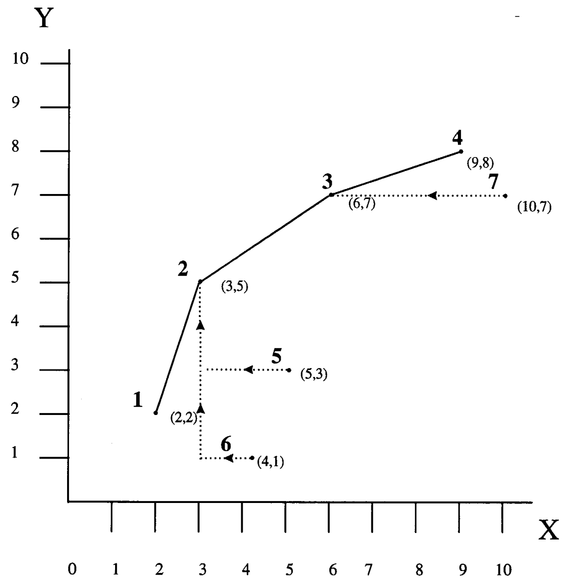

Figure A1. Envelopment surface

1) this furthermost point with non-negative slacks again occurs at DMU_2 (where $X_2 = 3$ and $Y_2 = 5$) with the *distance* of 5, computed as a nonzero input slack (since $X_6 > X_2$) of $4 - 3 = 1$ and a nonzero output slack (since $Y_2 > Y_6$) of $5 - 1 = 4$. If DMU_6 is to be efficient it has to conserve 1 unit of input X and augment output Y by 4 units.

For DMU_7 (where $X_7 = 10$ and $Y_7 = 7$) this furthermost point with nonnegative slacks occurs at DMU_3 (where $X_3 = 6$ and $Y_3 = 7$) with the *distance* of 4, computed as a nonzero input slack (since $X_7 > X_2$) of $10 - 6 = 4$ and a zero output slack (since $Y_2 = Y_6$). If DMU_7 is to be efficient it has to conserve 4 units of input X, but does not need to augment output Y.

The dual form yields an alternate geometric interpretation. Here the closest supporting hyperplane is sought, i.e., $\mu Y_k - \nu X_k + u_k = 0$. An efficient DMU_k (X_k, Y_k) will lie on the facet-defining hyperplane with equation $\mu^* Y_k - \nu^* X_k + u_k^* = 0$. A supporting hyperplane for DMU_3 is defined by the equation $3/2Y - 1X - 9/2 = 0$, and the coefficient values are taken from the row for DMU_3 in Table A2. These coefficient values are obtained from the solution to the linear program; taking the units of input and output for DMU_3 from Table A1 and substituting them for X and Y in the equation will yield an optimal solution to the equation for DMU_3.

As shown in Figure A1, DMUs 1–4 are efficient, while DMUs 5–7 are inefficient. For inefficient DMUs the objective function value w^* measures the distance to the closest supporting hyperplane. The supporting hyperplane for DMU_3 ($3/2Y - 1X - 9/2 = 0$) and the closest parallel hyperplane which passes through DMU_7 ($3/2Y - 1x - 9/2 = -4$) are a distance of 4 units apart. This is verifiable since, compared to DMU_3 where $X_3 = 6$, $X_7 = 10$ for DMU_7 giving an excess input consumption of 4. On the other hand, $Y_3 = Y_7 = 7$ for DMU_3 and DMU_7, and there is no shortfall in output production for DMU_7.