Dental Health Policy Analysis Series

An Economic Study of Expanded Duties of Dental Auxiliaries in Colorado

Tryfon Beazoglou, PhD, L. Jackson Brown, DDS, PhD, Subhash Ray, PhD,
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PREFACE

In the U.S. economy and elsewhere, productivity is an important concept. Analysts track changes in productivity and attempt to understand the underlying causes of such changes. Economists also believe that there are strong links between productivity and incomes. The U.S. government, through its Bureau of Labor Statistics, regularly measures and reports on productivity, not only to evaluate various sectors of the U.S. economy, but also to compare productivity across different countries. Economic analysis and public and private policy planning have always depended heavily on accurate measures of productivity.

It is essential for any industry or business, including dentistry, to understand the sources and effects of productivity. In 2006, the issues of delegation, expanded duty auxiliaries, and productivity were at the forefront of professional discussions—and they remain so in 2009. Thus, in 2006, the American Dental Association funded a timely study to measure the effects of delegation on productivity and efficiency of dental practices. Leading economists in the fields of health economics and productivity analysis were commissioned to design and conduct this project. Any good empirical study requires accurate data, and the acquisition of reliable data requires both resources and the willingness of individuals (subjects) to participate in the process. Since faculty members at the University of Colorado had conducted a previous study of delegation among Colorado dental practices, it was decided to build upon that study by collecting additional quantitative and qualitative data from Colorado dental practices.

Why focus on Colorado? First, Colorado is a unique state in terms of the discretion in delegation available to dentists. Second, the initial Colorado study had produced a group of dentists who had indicated a willingness to participate in further research. This provided a remarkable opportunity. The intent was to assess not only the contribution of auxiliaries to practices, but also the degree of delegation employed by Colorado dentists. Similar data had not been collected since the 1970s, so there was great enthusiasm among the economists commissioned to work on this project.

This study intended to quantify the relationship between delegation patterns and productivity; and therefore, capacity. The goal was to identify the most effective patterns of delegation, in terms of their impact on dental practice productivity. To do this, dentists were asked what treatment actions they delegated, the number of patients seen and procedures performed over a certain time period, the resources used to provide these services, and the gross billings generated. This allowed the researchers to calculate the effects on types and quantities of services delivered as well as the financial impact of different decisions about delegation on each dental practice.

The results of this study are unique and important. However, the researchers are well aware that empirical results, interesting as they may be, cannot fully account for the actual conditions faced by practicing dentists, nor can results of the study offer definitive recommendations about how each dentist can improve the delivery of services. Many factors influence the day-to-day conduct of a dental practice and the potential for delegation: physical practice size and the extent to which existing space and equipment are currently utilized, availability of personnel based on geographic location, willingness to train personnel and their willingness to be trained, the effective demand for oral health services in the geographic area of providers, and the dentist's personal preferences and choices regarding the style of practice. The purpose of this study was not to encourage or discourage a particular type of practice, but simply to analyze the empirical data and report the findings. Hopefully, the dental profession and other researchers will find this work worthwhile.

CONTRIBUTORS

This project was a joint collaboration of the American Dental Association and researchers at the University of Colorado and University of Connecticut. Researchers at the University of Colorado and HPRC staff collected data for this study. Economists from the University of Connecticut then analyzed the productivity and efficiency of each practice in the sample. Listed below are the names of the project team members by organization.

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This report is dedicated to Dr. Larry Meskin, an individual that did so much for all aspects of dentistry and was a mentor for so many in the profession. Dr. Meskin pioneered this project and played a vital role in all of its phases; sadly, he passed away in June of 2007 and did not see it come to fruition.

Special thanks go to Dr. L. Jackson Brown, former Associate Executive Director of the ADA's Health Policy Resources Center (HPRC), for having the vision and determination to undertake this important study of productivity for the dental profession by assembling knowledgeable researchers from the University of Colorado and the University of Connecticut.

While this study could not have been completed without the help and support of various staff members at the University of Colorado, the University of Connecticut and the ADA; the most important contributors were the Colorado dentists who participated in this research project. Without their time, commitment, interest and effort, the project would not have succeeded.

Lastly, a debt of gratitude is owed to the leadership of the ADA whose support made the project possible.

Table of Contents

List of Figures

List of Tables

An Economic Study of Expanded Duties of Dental Auxiliaries in Colorado

Background

Early Studies of Expanded Delegation

Past studies have indicated that delegation of some tasks during restorative procedures to allied dental personnel can increase the productivity of the dental team by permitting dentists to focus on the tasks that require a higher level of formal and clinical education. Several factors can modulate the expected gains in productivity. One factor is the extent of the delegation—that is, which subtasks in the overall restorative procedure are delegated. Original studies of expanded delegation focused on the reversible procedures that are required to complete the restoration after the restorative site is surgically prepared (Hammons, 1967, 1968; Hammons, Jamison, 1967; Lotzkar and Johnson, 1968; Lotzkar, 1968; Hammons and Jamison, 1968). These procedures include: placement of a matrix band, if indicated; securing a sufficient interproximal contact between the restoration and the adjacent tooth by placement of an interproximal wedge; final preparation of the restoration site by cleaning, placement of a baseliner and a cavity sealant; inserting restorative material in the prepared site; and shaping the inserted material for contour and occlusion.

Some of the early studies were time-motion types of studies (Lotzkar et al, 1971a, 1971b; Kilpatrick et al, 1972). When the patient was seated and the procedure started, timing of the procedure began. At the end of the procedure the time involvement of the dentist and each staff member was recorded. The results from these studies were convincing—increased delegation enabled greater production per unit of production time, using less dentist time. Since less expensive time of non-dentist staff was substituted for more expensive dentists' time, the unit cost of production also declined.

Other early studies were conducted in clinics where the flow of patients could be controlled, such as military installations and dental schools. One of the largest and best known studies established a clinic in Louisville, KY, specifically to study expanded functions. Such studies again demonstrated increased productivity with expanded functions. One of the few studies conducted in a less controlled environment studied expanded functions in a private practice in Lexington, KY (Mullins et al, 1983; Lange et al, 1982). This study was able to demonstrate an increase in output per hour while the practice was fully staffed. The results were more equivocal when one of the two dentists in the practice could not practice for an extended period of time.

Another study examined the effects of delegation on various factors including productivity, gross income, net income, and quality of care in private general practices in Washington State (Milgrom et al, 1983; Bergner et al, 1983). The results indicated that productivity increased in practices that delegated expanded functions more extensively. Higher practice gross incomes were associated with greater delegation; however, net income differences were not statistically significant. In terms of quality of care, researchers found that dental hygienists and dentists provided the same quality of restorative care with respect to amalgams, but dental hygienists tended to have more difficulty with composite restorations.

These classical studies of expanded delegation were conducted from the early 1970s through the early 1980s. They focused primarily on delegation of restorative procedures. Much has changed since these studies were completed. The epidemiology of dental caries has changed markedly. The percentage of patients that arrive at a dental office requiring multiple restorations has declined. The percentage that requires multiple restorations in one quadrant, the circumstance where delegation of the placement and finishing of amalgam demonstrated the greatest advance, has declined even more.

Thirty years ago, amalgam restorations represented the huge majority of all intracoronal restorations; and for posterior teeth, amalgam material was used almost exclusively. Presently, resin composite materials are commonly used when restoring posterior teeth. Composites are more technique-sensitive and require more education and experience before proficiency is attained. In addition, the procedures that are considered for delegation have increased. Preventive and prosthetic procedures are increasingly being delegated in states that permit such delegation.

CONTEMPORARY EXPERIENCE WITH EXPANDED DELEGATION

–Navy Dental Corps. The Navy Dental Corps utilizes both expanded function dental assistants and scaling technicians (Pebley, 1976). Use of these staff has increased productivity in their clinics, permitting more patients to be seen and releasing dentists for responsibilities that only they are qualified to perform. The quality of care has been maintained (Turner, 2006).

–Philadelphia Department of Public Health. In an oral presentation, R. Ivan Lugo, Dental Director, Philadelphia Department of Public Health, reported their experience with an expanded delegation program (Lugo, 2005). The program operates in seven clinics in the underserved areas of Philadelphia. The EFDA (Dental Techno Therapist) pilot program began in 1969. The full program was established in 1975. A high school degree was required to enter EFDA training for the program. Three hundred hours of chairside training or a formal training program were required of the EFDAs, divided between three weeks of didactic training and six months of clinical training. In addition, most of the EFDA's had prior dental assisting experience. Direct supervision of EFDAs was required. Key duties included: placement of rubber dams and matrix bands; placement of restorative material; medication as directed; and finishing and polishing of restorations. EFDAs also took study models and radiographs; provided patient education; and trained and supervised dental assistants.

Dr. Lugo reported that the program enabled the dental public health program to provide additional dental services by leveraging personnel. The expanded delegation improved output per dentist by 30% (output = workforce x productivity), resulting in an increase in additional patient visits and/or procedures. Quality of care has been sustained and no incidents or complaints involving services provided by EFDAs have been registered in the 30-year history of the program.

–Kansas. Several years ago the State of Kansas enabled dental assistants with the proper education and experience to perform not only coronal polishing, but also supragingival scaling (Mitchell et al, 2006). These personnel have permitted dentists to focus on higher level procedures, addressing a workforce shortage for dental hygienists in certain portions of the state and allowing dentists utilizing these assistants to see more patients each day. It appears that this has been done without compromising patient safety or care.

–Colorado. Perhaps the most extensive recent study of expanded delegation was conducted by researchers at the University of Colorado, School of Dentistry (Domer, 2005). The state practice act of Colorado permits a wide-range of expanded delegation. The study found that high delegation was strongly related to the number of patients seen during a year (high delegation-more patients). It was also related to the age of the dentist(s), whether or not the dentist had taken continuing education courses on the use of expanded function dental allied personnel, the number of dentists in the practice, and formal education of the expanded function staff.

When high delegation dentists were asked how delegation had affected their practice, they responded that they believed that expanded delegation had: (1) increased the number of patients seen, (2) increased productivity and income, (3) reduced the stress of practicing dentistry, and (4) permitted reduced hours without a decrease in income.

In contrast, low delegation practices reported that they chose to not delegate more due to lack of trained expanded function dental assistants and the higher salary these assistants normally require. They reported that they did not have the appropriate case mix, office size or design to appropriately utilize expanded function dental assistants. They also reported that they lacked time to educate and train the expanded duty assistant and were unsure how to integrate expanded delegation into their practices. For private practice, these results suggest that expanded delegation offers benefits for appropriate practices, but not all dentists believe expanded delegation would be useful for them.

COLORADO AS THE SITE FOR THE STUDY

This study builds on a previous Colorado study, *A Pilot Study to Determine Barriers to Implementing Productivity Enhancement Strategies in Dental Practices,* which was approved by the Santa Fe Group as part of its Oral Health

Care Scholars Program and funded by the American Dental Trades Association. The study was conducted by Dr. Larry R. Domer and Dr. Richard L. Call in spring of 2003. Colorado is an excellent site for the study because the range of procedures that can be delegated is among the most comprehensive in the U.S. Moreover, the state has permitted these forms of delegation for several years, so those practices that delegate have had time for that style of practice to be fully integrated into their operations. Practices that do not delegate also have had a substantial period to make that decision and have chosen not to delegate. Consequently, the reasons for both delegation and non-delegation among practices in the study will be based on several years of experience.

Goals and Objectives

The goals and objectives of this study were: to assess the effects of expanded duty dental auxiliaries on (1) dental output; and (2) the efficiency of general dental practices in Colorado. The specific objectives of this study were to:

(1) Compile and analyze results of the *2006 Survey of Expanded Duties for Dental Auxiliaries* conducted in Colorado;

(2) Identify and measure the structural determinants of productivity and efficiency in private dental practices in Colorado;

(3) Estimate the effect of various levels of delegation on gross billings, visits, value-added, efficiency, and net income of general dental practices; and

(4) Recommend specific steps general dental practices may take to increase their productivity and efficiency.

Methodology

SURVEY, SAMPLE AND DATA COLLECTION

We developed a survey instrument, the *2006 Survey of Expanded Duties for Dental Auxiliaries*, to address the primary goals of this study. We followed three approaches: (1) existing and widely used dental private practice survey instruments were examined; (2) national experts were consulted; and (3) the resulting survey instrument was pretested with general dental practices in Colorado. Appendix A contains the questionnaire.

The data collected from the initial Colorado study provided an existing sampling frame for this study. Many practices that were part of the initial study indicated their willingness to consider participation in a follow-up study through this question:

> Please check appropriate boxes
> ☐ 1. Please send me a copy of the survey results.
> ☐ 2. Yes, I would be willing to consider phase 2 participation but am not committing to it yet.

When the results of the first Colorado study were presented at the American Dental Association's Dental Economics Advisory Group (DEAG) meeting in March of 2005, Dr. L. Jackson Brown, chairman of DEAG and the Associate Executive Director of ADA's Health Policy Resources Center, expressed interest in the ADA collaborating with the University of Colorado School of Dental Medicine and the University of Connecticut in funding the continuation and expansion of the study in Colorado.

Thus, upon approval by the ADA's Board of Trustees, the second phase of this study—2*006 Survey of Expanded Duties for Dental Auxiliaries*—was funded by the ADA. Respondents of the Domer study who had indicated that they "would be willing to consider phase 2 participation" on their surveys were identified. The information from the first study allowed the practices to be stratified into high, medium and low delegation practices. This, in turn, allowed adequate numbers of each delegation pattern to be selected for the study.

The *2006 Survey of Expanded Duties for Dental Auxiliaries* was mailed as follows. On 10/25/2006, an introductory letter from the University of Colorado was mailed to 153 dentists. The survey and an accompanying cover letter were mailed from the ADA on 10/30/2006. Seventy responses were received. On 11/15/2006, an introductory letter from the University of Colorado was mailed to another 164 dentists. The survey and cover letter were mailed from the ADA on 11/17/2006. Sixty-two responses were received. On 12/28/2006, an introductory letter from the University of Colorado was mailed to another 86 dentists. The survey and cover letter were mailed from the ADA on 1/2/2007. Thirty-two responses were received. Thus, the total sample size was 403 (153+164+86) and the total number of respondents was 164. After accounting for dentists who were determined to be retired, deceased, not in private practice, and not locatable, the adjusted response rate was 43%.

The responses were reviewed for completeness and consistent entries. This process yielded 154 general dental practices with usable data. The 154 observations were divided into four groups based on the data provided regarding the hours worked among non-dentist staff—a key input in the production of dental services. (This was done because one of the methods of analysis used, Data Envelopment Analysis or DEA, requires non-zero entries for input variables. For example, if a practice did not indicate the hours of dental hygienists, then none of the other information provided by that practice could be used for DEA analysis or other techniques that require non-zero inputs.)

The first group consisted of all 154 practices (observations). For this group, the annual hours worked by dental hygienists, chairside assistants and other non-dentist staff were aggregated into one variable denoted as **dental auxiliary hours**. Among 131 of the 154 practices it was possible to disaggregate the dental auxiliary hours into two variables—dental hygienists plus chairside assistants' hours and other non-dentist staff hours. Among 117 practices, it was possible to completely disaggregate the dental auxiliary hours into three separate variables: dental hygienist hours, chairside assistant hours and other non-dentist staff hours. The fourth group consisted of 81 respondents who, aside from filling out the survey, also provided detailed practice production information using their practice management systems. While all methods of analysis were applied to all groups, only the results for the first group of 154 are presented in this report.

RELEVANT THEORY

Economists distinguish between total output, productivity, and efficiency. These terms and some related concepts are described below. In addition, Appendix B contains a more detailed discussion.

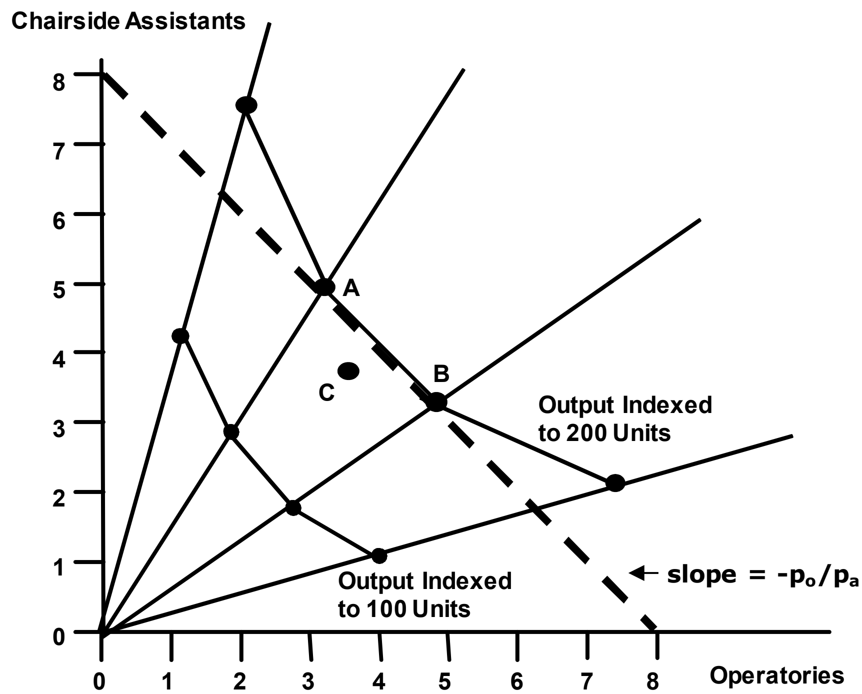
–Output. Economic studies of dental practices generally measure output in several ways: visits, gross billings, value-added, and quantities of various services. Each measure has some validity as well as certain drawbacks. Number of visits is normally the easiest to measure, but visits vary in length as well as the volume and types of services delivered. Gross billings are a more comprehensive measure of services produced but reflects service prices as well as quantities. Strictly speaking, output should be measured in quantity terms, but gross billings can be viewed as a price-weighted index of output. A detailed breakdown of various types of services is arguably the best measure of output, but many of the techniques used to analyze production rely on a single measure of output. The survey described above collected information on each of these output measures.

–Productivity. Productivity generally refers to output per unit of some input (e.g., gross billings per dentist or per hour of dentist time), or output relative to some index of input use (e.g. visits per dollar of total cost, where total cost is interpreted as a price-weighted measure of input use). If, through the elimination of inefficiencies or through the genius of a new method of production, greater output is created by the same set of inputs, an improvement in productivity has occurred. In contrast, improvements in production generally mean that more inputs are fed into the process, yielding greater output. This is an important distinction because an increase in productivity implies a greater capacity to produce with a fixed amount of resources. An increase in production simply means that more resources are employed within the same process. (For more details on productivity and its measurement see Appendix B.)

–Efficiency. *Technical efficiency* refers to the producer's ability to achieve the highest attainable output from a particular mix of inputs, given the current "technology" of production. This approach translates into the analysis of efficient combinations of staff and equipment. Once existing staff and equipment are most efficiently combined, the capacity of the delivery system is determined. Production is expanded only with the addition of more staff or more equipment. The limitation on capacity to produce, given an efficient combination of inputs, is called the production limit or frontier for that combination of staff and equipment.

Figure 1 helps to illustrate the production theory concepts within the context of a two-dentist practice that, besides the dentists' time, uses operatories and chairside assistants to produce gross billings (or some other measure of dental service output). For simplicity, the example assumes that the two inputs are "lumpy" (integer-valued or indivisible), but most economic analyses of production treat inputs and outputs as continuous variables. In the hypothetical two-dentist practice shown in Figure 1, 100 units of output can be produced with several different input combinations. Similarly, several input combinations can be used to produce 200 units of output. Economists refer to each of these output contours as an *isoquant*—a locus of input combinations that can produce the *same* level of output. Isoquants further from the origin reflect higher levels of output. We only show two isoquants here, but a complete map of isoquants—one for each potential level of output—describes the existing production process or *technology*.

Figure 1: Production Isoquants for a Two-Dentist Practice



Again, technical efficiency implies that the maximum possible output is produced from a chosen bundle of inputs. In the graph, that simply means operating on one of the many isoquants that characterize the technology. So what does it mean to be technically *inefficient*? Again, suppose that the isoquants in Figure 1 reflect the state-of-the-art technology for a two-dentist practice. But, suppose that a practice currently using 3 operatories and 6 assistants produces only 175 units of output rather than the 200 that are possible. This practice would be deemed *technically inefficient*. One of the methods used in this study, Data Envelopment Analysis or DEA, allows us to identify a group of efficient practices and then compare other inefficient practices to this benchmark group. The technique also yields an index, ranging from zero to one, which measures the degree of efficiency for each practice in the sample. Appendix B gives a more formal exposition of DEA and the index of efficiency.

All of the points on the contours are *technically efficient* input combinations, but they are not all *economically efficient*. In this example, an economically efficient input mix is determined by the input prices (relative costs) of assistants (p_a) and operatories (p_o). The dotted *isocost* line, tangent to a segment of the outer contour, displays a ratio of operatory cost to assistant cost which indicates that any of the combinations along that line segment, including the points A and B, are economically efficient ways for this two-dentist practice to produce 200 units of output. The slope of the isocost line = $-p_o/p_a$, so as the input price-ratio changes, the economically efficient mix of inputs also changes. A steeper isocost, reflecting a higher operatory price relative to the price of an assistant, would make only point A, with fewer operatories and more assistants, economically efficient. A slightly flatter isocost, caused by a decline in the operatory price relative to the price of an assistant, would make point B the only economically efficient combination. While technical efficiency simply means using the existing technology to get the most from a chosen mix of inputs, economic efficiency further requires that the chosen input mix is the least costly way to produce that output.

Note that the number of dentists in this example has been held constant. If we consider a solo practice, instead of the two-dentist practice in the example, the entire set of isoquants will shift (one dentist can normally produce less with a given combination of operatories and assistants), but the same basic principles apply: (1) inputs can be substituted (to some extent) to attain a particular level of total output; (2) when technical efficiency is achieved, the practice is operating on one of the isoquants, and any increase in output (movement to a higher isoquant) requires more of at least one input; (3) the cheapest way to produce a given level of output depends on the relative prices of inputs; and (4) as input prices change, the economically efficient mix of inputs also normally changes, requiring more use of the input that has become relatively cheaper and less use of the input that has become relatively more expensive.

The graph is a hypothetical example of a two-dentist practice and is not intended to represent actual production configurations. Other types of staff, such as dental hygienists and front office personnel, as well as various equipment and supplies, also play a role in the efficient production of dental services. These additional inputs to the production process cannot be shown in a two-dimensional graph: the underlying assumption is that other inputs are held constant. In actual production analysis, all of these inputs are considered simultaneously by using multivariate functions and mathematical techniques (see Appendix B).

–Scale Properties. Another property of the production process is *returns to scale*. Returns-to-scale describes the effect on output of a proportionate change in all resources. For example, in Figure 1, for each input combination that produces 100 units of output, if a doubling of inputs exactly doubled output to 200 units, this would indicate a *constant returns to scale*. If this same "scaling up" of inputs increased output *more* than proportionately (e.g., to 225 units), this would be an example of *increasing returns to scale*. A less than proportionate increase in output (e.g., to 175 units) would indicate *decreasing returns to scale*. (Technically, the diagram is not an ideal illustration of returns to scale, since the input that is not being graphed, the number of dentists, is fixed.) In this study, our estimates of the *production function*—the multivariate relationship between output and various inputs—quantifies the contribution of each input, as well as the returns to scale for dental practices in the sample.

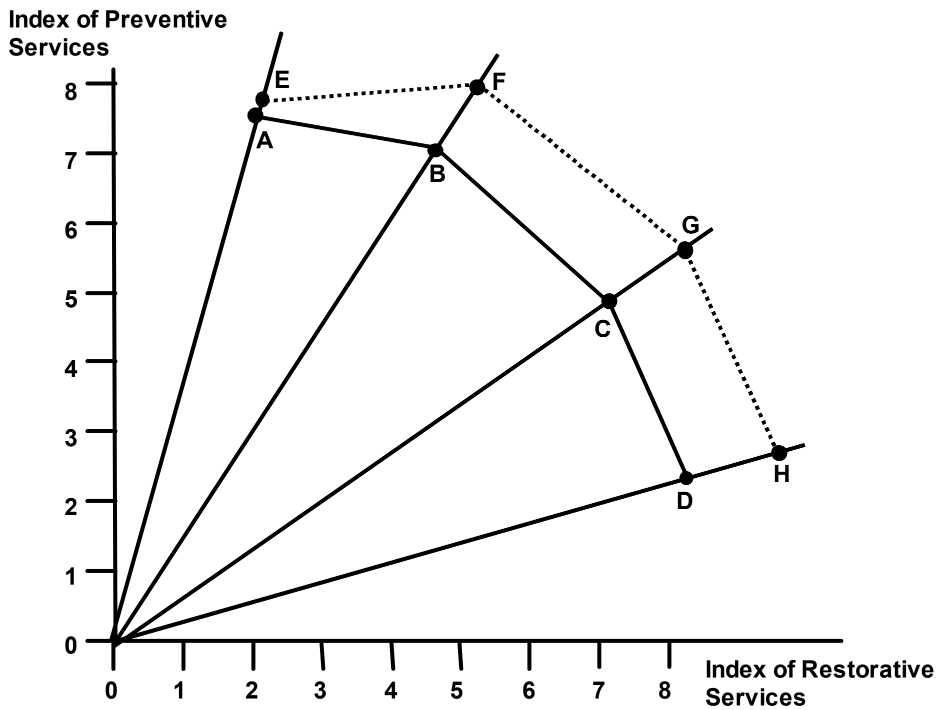
–Productivity with Expanded Function Dental Auxiliaries. The same production principles apply when considering expanded responsibilities for dental auxiliary personnel. In production terms, this is equivalent to a further division of labor, or at least a reassignment of tasks: a larger number of procedures are delegated to non-dentist staff. There are two possible gains that might be realized from expanded delegation. First, it permits dentists to focus on procedures that require their expertise and training, while the auxiliary handles some procedures previously done by the dentist. This can enhance the production of a practice per unit of time and increase technical efficiency. Equivalently, this potential gain from expanded delegation might allow the two-dentist practice depicted in Figure 1 to produce the same 200 units of output with fewer inputs, as represented by point C inside the 200-unit isoquant. A second benefit from expanded delegation is economic efficiency. By substituting the less costly time of expanded function auxiliaries for the more costly time of dentists, a potential cost saving can be realized. So not only is more dentistry produced per hour of production, but it also may be produced with a less expensive mix of labor inputs.

This discussion assumes that all aspects of the underlying technology of production, except the staff scope of responsibilities remains the same between an expanded function and a traditional dental practice—that is, materials, operatories, dentists' abilities etc. are similar in both types of practices. But, expanded delegation, if effective, may yield more services from the same bundle of inputs for practices with certain types of case mix. This increased efficiency, if it exists, will affect the production that is possible for a dental practice of a given size.

This concept is illustrated in Figure 2 which shows hypothetical production possibilities for traditional and expanded delegation practices. For this illustration, practices with different proportions of preventive versus restorative services are depicted. The upper-left radiating line indicates a largely preventive practice, while the lower-right radiating line indicates a largely restorative practice. The two intermediate lines show intermediate preventive/restorative proportions. The solid line connecting the radiating lines depicts the production frontier for traditional practices A, B, C, and D (no expanded delegation). The ABCD line represents the most production that can be produced with efficient traditional practices. The dashed line connecting practices E, F, G and H represents a hypothetical production frontier for expanded delegation practices.

Both traditional and expanded practices cannot be beyond their respective production possibility frontiers. The graph assumes that expanded delegation is more efficient for restorative services but not significantly more efficient for preventive services. This is the reason that the dashed production frontier for expanded-delegation practices diverges from the solid production frontier for traditional practices for those practices with a higher proportion of restorative services.

Figure 2: Production Possibilities



Notice further, for preventive practices (the upper left-most dots), there is not much difference between traditional and expanded delegation practices that are both efficient. This is because under this hypothetical example, the efficiency gain for preventive services is not large for expanded-delegation practices. In contrast, for predominately restorative practices (the lower right-most dots) the difference is greater between traditional and expanded-delegation practices of about equal efficiency for their type of practice. This illustrates a large payoff in efficiency for efficient, expanded delegation practices over traditional practices.

Of course, this is only a hypothetical example for illustrative purposes. These assumptions may or may not be true. The study is intended to provide evidence to help make an empirical determination of these efficiency relations.

–Costs of Expanded Function Dental Auxiliaries. If expanded function auxiliaries command higher earnings, these additional costs must be weighed against the potential gains in practice output and income, but there are other potential costs associated with expanded delegation.

While the underlying technology may not change, the size of the staff and the number of operatories to fully utilize that staff is likely to be larger for an expanded delegation practice than for a traditional practice with the same number of dentists. If expanded practices are systematically larger, the analysis will need to control for such differences to provide an appropriate comparison. Other aspects of staff size also will need to be considered. Larger staff size increases the overhead per hour. If production using expanded delegation is large enough, the practice can absorb the increase in hourly operating costs and still generate more net income per hour of production. Similarly, the cost per unit of dentistry produced will be lower in the expanded practice if the increase in output is proportionately larger than the increase in practice costs.

If expanded delegation increases operating cost, there is another potential downside. Every period of non-production (down time) costs the expanded practice more than it does the traditional practice. Consequently, it is important to have a reliable flow of patients to keep the staff and equipment fully utilized in an expanded delegation practice. Broken appointments, bad weather days, equipment breakdowns, staff absences, and dentists' time-off place a greater burden on an expanded practice. Scheduling also becomes more complicated. Not only must the appointment schedule be fully booked, perhaps slightly overbooked to ensure continuity of production, but appointments must be scheduled such that not too many requiring expanded delegation overcrowd a specific time slot.

DEFINITIONS AND MEASURES

–Output Measures. To assess the productivity and efficiency of dental practices, we used three single-output measures: number of patient visits, gross billings and value-added. Value-added is defined as the dollar value of dental practice output (gross billings) minus the dollar value of inputs purchased from other firms (in this study the dollar value of these inputs consists of lab expenses and dental supplies).

–Input Measures. The set of input measures used for the production function specification as well as the Data Envelopment Analysis (DEA) included: annual hours worked by dentists, dental hygienists, chairside assistants and other non-dentist staff, laboratory expenses, supply expenses, number of operatories and square feet of office space. Because laboratory and supply expenses are measured in dollars rather than physical units, they are not "inputs" in the usual sense, but they serve as good proxies for the quantities of these inputs if lab fees and the prices of supplies are roughly the same for all practices in the study. This is more likely to be true within a single state like Colorado than across many states.

–Delegation Measures. Using the responses to three questions on the survey (Q20, Q23 and Q23 in conjunction with Q25), three separate measures for the delegation of expanded duties were calculated. (See Appendix A for a copy of the survey instrument.)

(1) A qualitative variable was created using the responses to Question 20 which asked: *Do you currently use, or at one time used, expanded function auxiliaries in your primary practice location?* The qualitative variable was assigned a value of "1" if the answer was, "*Yes, currently use*." The qualitative variable was assigned a value of "0" if the answer was, "*No, never used" or "Yes, once used but have discontinued."*

(2) A simple average index was calculated based on the responses to Question 23 which asked dentists to indicate the percentage of delegation for various procedures/activities within eight categories of services. The procedures listed under the category of *Diagnostic/Preventive/Adjunctive* in Question 23 were not used in the calculation because almost all sampled practices delegated these procedures; hence, they do not provide much information about *expanded* delegation. The three categories of *Endodontics, Oral Surgery and Other* were combined into one category; resulting in five service categories. The simple average delegation index was constructed by first calculating the average response rate in each category (rendering 5 means), and then calculating an overall average.

(3) A weighted average delegation index was constructed the same way as the simple average delegation index. For this calculation, however, the means of the five categories were weighted by their corresponding shares of the practice gross billings as indicated in Question 25.

METHODS OF ANALYSIS

Several analyses were performed to achieve the goals and specific objectives of this study.

–Descriptive Analysis. Descriptive analyses (univariate and bivariate) of the structural characteristics and level of delegation of expanded duties were performed.

–Production Function Analyses. The methodology used to assess the effects of expanded delegation on dental output was done in two steps. In the first step, a production function was specified to estimate the contribution of key inputs involved in the production of a general dental practice, excluding the delegation of expanded duties variables. In the second step, the production function was modified to include a variable measuring the extent of delegation. These two steps, which are described in detail below, allowed an assessment of the independent contribution of delegation on dental output.

–Production Function and Empirical Specification. Using a standard econometric approach to estimate the contribution of key inputs to dental practice outputs involved the empirical estimation of a dental production function. In general, a production function is a functional relationship between measure(s) of output(s) and a vector of inputs. For this study, we used a Cobb-Douglas production function:

$$O = b_0\, DH^{b1}\, DSH^{b2}\, C^{b3}.$$

This function is linear in logarithms:

$\ln O = b_0 + b_1 \ln DH + b_2 \ln DSH + b_3 \ln C$

where O is dental output, b_i are parameters to be estimated, DH and DSH are annual hours of work for dentists and dental staff (includes dental hygienists, chairside assistants, and other dental staff) and C is the number of dental operatories; ln is the natural logarithm.

A modified Cobb-Douglas production function was used to assess the effects of expanded duties dental auxiliary delegation. The modification consisted of adding to the Cobb-Douglas production function a variable indicating the level of expanded duties which were delegated to dental auxiliary:

$O = b_0\, DH^{b1}\, DSH^{b2}\, C^{b3}\, e^{b4DEL}$, or in logarithms:

$\ln O = b_0 + b_1 \ln DH + b_2 \ln DSH + b_3 \ln C + b_4\, DEL$

where **e** is the base of the natural logarithm and **DEL** the level of delegation.

–Effects of Delegation on Output. We used three alternative measures of dental output: gross billings (market value of dental services), dental visits and value-added (defined as gross billings minus laboratory expenses and supplies).

We used three alternative measures for the level of delegation. These were described above. The first measure of DEL is a qualitative variable taking a value of "1" (if the practice delegates expanded duties) or "0" (if the practice does not delegate expanded duties). The second measure of DEL is a simple average score of the expanded duties delegated in a practice. The third measure of DEL is a weighted average score of the expanded duties delegated in a practice (where the weights are the share of dental services with respect to total gross billings).

The method of estimation was ordinary least squares. The estimates enabled us to establish the incremental contribution of the various factors (i.e., dentist hours, auxiliary hours, operatories) including level of delegation to dental outputs. We used these results to estimate the expected increase in outputs, if a dental practice increased (decreased) the number of operatories, auxiliary hours, etc.

–Effects of Delegation on Efficiency. Clinical (or technical) efficiency is defined as the effectiveness with which a given set of inputs (e.g., dentist and auxiliary time, operatories, lab expenses, supply expenses) are used to produce outputs (e.g., gross billings, dental visits, value-added). To assess the effects of expanded delegation on the clinical efficiency of a general dental practice, a two-step process was used. In the first step, we specified and estimated the clinical (technical) efficiency of each dental practice, excluding the variable measuring the delegation of expanded duties. The method of estimation is

Data Envelopment Analysis (DEA). Thus, the first-step DEA consists of a series of mathematical programming problems—one for each practice in the sample. And the solution, gives an efficiency score ranging from 0 to 1, with 1 indicating that the practice is operating somewhere *on* the efficiency frontier constructed from the observed behavior of practices in the sample. Three sets of efficiency scores were generated for the sampled dental practices, a set for each measure of output: gross billings, dental visits, value-added.

Note that DEA is an alternative to standard production function analysis (Ray, 2004). Dental practices vary in size, composition, and management structures (i.e., inputs), and this variation impacts their effectiveness in producing patient care services (i.e., outputs). To identify best practices, we used DEA—which has been applied to a variety of private and public sector production processes, including dental services (Buck, 2000; Wang et al, 2002; Coppola et al, 2003; Widstrom et al, 2004).

DEA allows for multiple inputs and is a nonparametric approach that does not require a pre-specified functional form to describe the link between output and various inputs. These features allow the data to "tell the story" rather than imposing unnecessary and sometimes arbitrary restrictions. DEA also ensures that all observations lie within the constructed technology set and, therefore, comes closer to the notion of the production function as a performance boundary. Appendix B contains detailed information on DEA.

In the second step of DEA, a set of linear regressions were estimated to assess the impact of expanded duty delegation on practice clinical efficiency. The dependent variable in each set of regressions was the efficiency score of each practice using as output measure gross billings, dental visits and value-added, respectively. The independent variables included the level of delegation (the same three measures of delegation as in the modified Cobb-Douglas production function specification) as well as other dimensions associated with a dental practice, such as location, staff and patient characteristics as follows:

List of Variables	**Variable Definition**	**Data Source**
Training	Dentists were asked if they had taken any CE courses focusing on the use of expanded functions for auxiliaries.	Question 5 in survey instrument
% No-show	Dentists were asked to estimate the percent of all scheduled appointments for which the patient did not appear.	Question 12 in survey instrument
% of gross from uninsured patients	Dentists were asked of the gross billings collected, what percent was received from uninsured patients.	Question 18a in survey instrument
% White	U.S. resident White population at the zip code level	Census 2000
% with BA degree	Percent of the population with a bachelor's degree at the zip code level	Census 2000
Per capita income	Per capita income at the zip code level	Census 2000
Dentist/square mile	Number of dentists per square mile based on zip code of practice locations	ADA & Census 2000

–Effects of Delegation on Net Income. One important issue of delegating expanded duties to dental auxiliaries is to assess their impact on the net income of a general practice. If expanded function auxiliaries command higher earnings, these additional costs must be weighed against potential gains in revenues (gross billings). A proper way to assess the impact of expanded function dental auxiliaries in a dental practice would be to specify and estimate a profit function. Such a specification would require input and output prices, the objective function of the dental practice, the level of training of dentists and dental auxiliaries as well as a number of other intangibles; information that was not part of this study. Thus, an ad hoc linear regression model was estimated. Two dependent variables were used: practice net income and practice net income per dentist hour. The independent variables included level of delegation and patient and practice characteristics (see list of variables above).

Results

DESCRIPTIVE STATISTICS

Of the 154 dentists, 141 were male and 13 were female. The overall average age of the group was 50.4 years. Female dentists were younger, with an average age of 45.6 years, compared to 50.9 years for male dentists. The overall average number of years since graduation was 22.7 years. Among the 13 females, this average was 13.9 years compared to 23.6 years among their male counterparts.

Dentists were asked if they had graduated from either a General Practice Residency (GPR) or Advanced Education in General Dentistry (AEGD) program. The majority, 80.5%, said "No," 16.9% said they had graduated from a GPR program and 2.6% said they had graduated from an AEGD program. The majority, 90.9%, also indicated that they had not taken any continuing education courses focusing on the use of expanded functions for auxiliaries in the "past three years."

Among the 154 dentists, the average number of non-dentist full-time (32 hours or more per week) staff was 4.7 and the average number of non-dentist part-time (less than 32 hours per week) staff was 1.8. Of the 154 dentists, 102 (or 66.2%) indicated being solo practitioners.

The average length of a scheduled appointment was 57.3 minutes and the average percentage of "no-shows" for scheduled appointments was 6.7%. Responding dentists estimated that patients under the age of 18 accounted for 15.4% of their patient base; patients 18 to 34 years of age accounted for 19.9%; those who were 35 to 64 years of age accounted for 51.8%; and those who were 65 and older accounted for 13.0% of the patient base.

As mentioned previously, dentists who were contacted for this study had participated in a previous 2003 study. During that study, these 154 dentists were categorized as follows: 30 (19.5%) were found to be "high" delegators; 28 (18.2%) were "medium" delegators; 88 (57.1%) were "low" delegators; and 8 (5.2%) were not assigned a delegation level. In the 2003 study, the low delegation level included those who only delegated diagnostic/preventive services; medium delegation level included those who delegated crown/bridge services but not restorative services; and high delegation level included those who delegated restorative services.

Tables 1-3 describe the characteristics of the responding dentists' practices. Among the 154 practices, the average gross billings for 2005 were $859,761. Annually, an average of about $58,000 and $52,000 were spent on lab expenses and dental supply expenses, respectively. These practices had an average of 5,365 patient visits per year, and dentists spent an average of 2,289 hours per year in their practices. As shown in Table 2, the majority of the 154 respondents were solo practitioners; none had more than six dentists. About 55% of the respondents had 3 or 4 operatories; 15.6% had more than 6 operatories (Table 3).

Table 1: Descriptive Statistics of Sampled General Dental Practices

(N=154)	Mean	Std. Deviation	Minimum	Maximum
Gross Billings (2005)	859761	647301	98343	3594756
Practice Net Income	283952	252522	39000	1600000
Annual Visits	5365	4222	784	25991
Number of Dentists	1.6	1.0	1	6
Dentist Hours	2289	1454	800	9214
Dental Hygienist Hours	1992	1638	0	8820
Chairside Assistant Hours	3285	2468	0	13500
Other Staff Hours	2849	2645	0	16400
Dental Auxiliary Hours	8126	5432	1470	31448
Square Feet	2064	1407	800	13000
Number of Operatories	4.6	2.5	1	20
Lab Expenses	57893	45719	4000	300000
Dental Supply Expenses	52253	44958	3676	236816
Value-Added	749615	568006	68556	3236452

Table 2: Distribution of the Number of Dentists in the Practice

Number of Dentists	Frequency	Percent
1	102	66.2%
2	33	21.4%
3	11	7.1%
4	3	1.9%
5	3	1.9%
6	2	1.3%
Total	154	100%

Table 3: Distribution of the Number of Operatories in the Practice

Number of Operatories	Frequency	Percent
Less than 3	15	9.7%
3	39	25.3%
4	45	29.2%
5	22	14.3%
6	9	5.8%
More than 6	24	15.6%
Total	154	100%

LEVEL OF DELEGATION

Two questions on the survey instrument dealt with delegation. In one question (Q20), dentists were asked if they currently use, or at one time used, expanded function auxiliaries in their primary practice locations. The results are shown in Table 4. Almost two-thirds (63.6%) of the respondents delegated some activities to their auxiliary staff.

Table 4: Distribution of Responses to the General Delegation Question

Q20: Do you currently use, or at one time used, expanded function auxiliaries in your primary practice location?	**Number**	**Percent**
Yes, currently use	98	63.64%
Yes, once used but have discontinued	17	11.04%
No, never used	39	25.32%

Table 5 presents mean characteristics of practices based on whether or not the responding dentists indicated currently using expanded function auxiliaries in Question 20. Recall that the categories of "*Yes, once used but have discontinued*," and "*No, never used*" in Q20 were combined to indicate no delegation. The differences between the two groups in Table 5 were statistically significant for all variables except "other staff hours."

Table 5: Mean Characteristics of Dental Practices, by Delegation

	Delegation=No (N=56)	**Delegation=Yes (N=98)**
Gross Billings (2005)	602990	1006487
Practice Net Income	209825	326311
Annual Visits	3680	6328
Number of Dentists	1.3	1.7
Dentists Hours	1915	2502
Dental Hygienist Hours	1429	2314
Chairside Assistant Hours	2437	3769
Other Staff Hours	2434	3086
Dental Auxiliary Hours	6301	9168
Square Feet	1717	2261
Number of Operatories	3.7	5.1
Lab Expenses	39296	68520
Dental Supply Expenses	36793	61088
Delegation Index, Simple	17.31	39.50
Delegation Index, Weighted	8.59	32.88

In another more detailed question (Q23), dentists were asked of all the times specific procedures/ activities were performed, approximately what percentage were delegated to chairside assistants or dental hygienists. Table 6 shows the mean percent of each procedure/activity delegated to the dental auxiliaries. For example, the mean percentage level of delegation was 90% or more for the listed diagnostic and preventive services. The one exception was for the placement of occlusal sealants where the mean percentage delegated was 66%. The mean percentage of delegation was 33% or more for restorative procedures listed under the "Operative, Primary and Permanent Teeth" category and 46% for the placement of temporary filling materials. And so on.

It should be noted that the scope of procedures/activities listed in Table 6 which are allowed to be delegated by a dentist to auxiliary staff (i.e., hygienists, chairside assistants) is the broadest in the country. With the exception of the procedures/activities listed under the category of Diagnostic/Preventive/ Adjunctive, very few states allow some of the other procedures to be delegated to auxiliary staff.

Since the question did not specify to which dental auxiliary procedures/activities were delegated, the last column in Table 6 groups the procedures/activities according to four categories: two categories for dental hygienists and two categories for chairside assistants. The final category is those procedures rarely performed by a non-dentist anywhere in the U.S. outside of Colorado. The procedure/activity coding guide for the last column is as follows:

Most assistants in the U.S. perform
Assistants in a few other states other than Colorado perform
Most hygienists in the U.S. perform
Hygienists in some states other than Colorado perform
Rarely performed by auxiliary staff outside of Colorado except at federal facilities

The reader should note that the procedures/activities with blue shading can also apply to dental hygienists. For example, local anesthesia can be a function for a hygienist or an assistant. Dental hygienists are more likely to provide local anesthesia; in those jurisdictions where they can provide sub-gingival scaling, they usually can provide local anesthesia. In jurisdictions where they cannot provide sub-gingival scaling, they frequently cannot provide local. The authors are unaware of any state, including Colorado, where dental hygienists can provide 'block' locals—it is usually limited in 'infiltration' locals. Chairside assistants can sometimes provide 'infiltration' anesthesia.

Lastly, it may be important to point out that within the last several years, there has been significant blurring in the scope of services that can be provided by chairside assistants and dental hygienists—and with the implementation of new workforce models, things become even less clear. The color-coding guide in Table 6 does not address these issues and is only provided as a general reference for the reader.

Table 6: Mean Level of Delegation by Procedure/Activity

	Number	Mean Percent
Diagnostic/Preventive/Adjunctive		
Take PA or BW radiographs	154	95.93%
Take panoramic radiographs	109	97.96%
Provide prophylaxis	143	91.69%
Place occlusal sealant(s)	111	66.88%
Administer topical fluoride	146	97.48%
Apply fluoride varnish	97	94.24%
Take and pour alginate impressions	149	87.82%
Operative, Primary and Permanent Teeth		
Place wedge/matrix for amalgam	72	33.67%
Place/finish amalgam (1 surface)	62	38.24%
Place/finish amalgam (2+ surfaces)	60	36.23%
Place/wedge matrix for composite	84	35.89%
Place/finish anterior composite	69	37.97%
Place/finish posterior composite (1 surface)	77	38.38%
Place/finish posterior composite (2+ surface)	74	34.04%
Place temporary filling material	114	46.08%
Fixed Prosthodontics		
Place cord for a C&B impression	93	52.91%
Take final C&B impression	72	37.10%
Make temporary crown	123	70.70%
Cement temporary crown	129	69.19%
Remove temporary crown	122	68.21%
Adjust permanent crown before cementation	74	48.28%
Cement permanent crown	61	32.97%
Initial placement/adj of stainless steel crown	39	23.33%
Cement stainless steel crown	42	35.95%
Make temporary bridge	95	67.53%
Cement temporary bridge	101	70.80%
Remove temporary bridge	106	66.75%
Adjust permanent bridge before cementation	67	43.21%
Cement permanent bridge	59	28.64%
Removable Prosthodontics		
Take preliminary RPD impression	124	80.03%
Take final RPD impression	70	48.39%
Try RPD framework in mouth	59	30.32%
Take preliminary CD impression	105	74.57%
Take final CD impression	61	35.72%
Take records for CD	57	29.11%
Adjust RPD or CD	80	36.69%
Rebase, reline, or repair denture	68	36.53%
Periodontics		
Place subgingival medicaments	102	75.02%
Scaling, root planing, and/or curettage*	128	90.30%
Endodontics		
Medicate root canal	41	9.93%
Obturate root canal	38	1.32%
Oral Surgery		
Place suture	42	0.24%
Remove suture	98	45.91%
Other		
Adjust orthodontic appliance	28	27.50%
Place or remove orthodontic brackets/wires	21	45.95%
Local anesthesia	91	17.53%
Perform brush biopsy	37	23.00%

* Supragingival is common; subgingival is not as common in other states.

Based on the reported percent delegation of the procedures listed in Table 6, two overall indices of delegation were created:

▪ The first is the simple average across all activities, with a mean value of 31.43%.

▪ The second is a weighted average (the weights being the shares in gross billings of category of services) across all activities, with a mean value of 24.05%.

Recall that these indices do not include the percent response to the procedures/activities listed in the first category of services, that is, Diagnostic/Preventive/Adjunctive. To put these indices in perspective, Tables 7 and 8 present the frequency distribution of each index.

Table 7: Frequency Distribution of Delegation Index, Simple Average

% Functions Delegated	Number	Percent
Less than 15	31	20.1%
15.00 - 24.99	32	20.8%
25.00 - 34.99	29	18.8%
35.00 - 44.99	26	16.9%
45.00 - 54.99	17	11.1%
55.00 and Over	19	12.3%
Total	154	100.0%

Table 8: Frequency Distribution of Delegation Index, Weighted Average

% Functions Delegated	Number	Percent
Less than 15	72	46.8%
15.00 - 24.99	30	19.4%
25.00 - 34.99	12	7.8%
35.00 - 44.99	12	7.8%
45.00 - 54.99	12	7.8%
55.00 and Over	16	10.4%
Total	154	100.0%

Production Function Results

Tables 9-11 present the regression results of the Cobb-Douglas production function using gross billings, value-added and visits as output measures. With respect to input measures, delegation is initially excluded so that its impact can be measured in the modified production function (Tables 12-14). The results in Tables 9-11 show that the inputs of dentist hours, auxiliary hours and number of operatories are all positive and statistically significant. The positive statistically significant coefficient of an input indicates that a unit increase in that input will result in a unit increase in the dependent variable (gross billings, value-added, and visits)—all other inputs remaining constant.

In addition, note that the sum of the estimated input coefficients of each production function (gross billings, value-added, visits) is greater than one. In fact, they are 1.244, 1.245, and 1.235, respectively (testing for statistical significance, all three values were found to be statistically different than one). Recall from the previous discussion of scale properties that when "scaling up" of inputs increases output *more* than proportionately, *increasing returns to scale* are exhibited. In other words, among these 154 dental practices, an increase in all inputs (dentist hours, auxiliary hours, and operatories) by, say, 10% would lead to an increase in dental output (gross billings, value-added, visits) by about 12.5%.

Table 9: Estimated Cobb-Douglas Production Function, Dependent Variable = Gross Billings

Variable	Coefficient	Std. Error	t-value	Prob > |t|
Constant	6.157	0.530	11.623	0.000
Dentists Hours	0.294	0.072	4.105	0.000
Auxiliary Hours	0.501	0.060	8.354	0.000
Operatories	0.449	0.080	5.644	0.000

R-square=0.807, F=208.837, N=154

Table 10: Estimated Cobb-Douglas Production Function, Dependent Variable = Value-Added

Variable	Coefficient	Std. Error	t-value	Prob > |t|
Constant	6.004	0.551	10.894	0.000
Dentists Hours	0.287	0.075	3.878	0.000
Auxiliary Hours	0.507	0.062	8.124	0.000
Operatories	0.449	0.083	5.431	0.000

R-square=0.795, F=193.868, N=154

Table 11: Estimated Cobb-Douglas Production Function, Dependent Variable = Visits

Variable	Coefficient	Std. Error	t-value	Prob > |t|
Constant	1.531	0.609	2.515	0.013
Dentists Hours	0.399	0.082	4.843	0.000
Auxiliary Hours	0.354	0.069	5.135	0.000
Operatories	0.482	0.091	5.280	0.000

R-square=0.742, F=143.552, N=154

Tables 12-14 present the results of the modified Cobb-Douglas regressions estimating the effects of expanded duties dental auxiliary delegation on gross billings (Table 12), value-added (Table 13) and visits (Table 14). Each Table shows the results of three regressions based on using the three measures of delegation: the qualitative variable (Regression 1), the simple average score (Regression 2) and the weighted average score (Regression 3).

In all of the modified Cobb-Douglas regressions, regardless of the output measure used, the estimated coefficient of the inputs of dentist hours, auxiliary hours and number of operatories as well as the delegation measures are all positive and statistically significant. Comparing the results with respect to the three delegation measures, note that while the coefficients of the two delegation variables represented as indices are smaller than the coefficient of the qualitative variable, the delegation indices are representing percentages. In terms of statistical significance, the weighted average index is less significant than the other two delegation measures.

Lastly, the estimated input coefficients in the set of Cobb-Douglas production functions (Tables 9-11) are similar to these corresponding modified Cobb-Douglas production functions (Tables 12-14). In other words, delegation seems to exert an additional and independent effect on dental output.

Table 12: Estimated Modified Cobb-Douglas Production Function, Dependent Variable = Gross Billings

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	6.135	0.524	11.709	0.000
	Dentists Hours	0.304	0.071	4.277	0.000
	Auxiliary Hours	0.493	0.059	8.295	0.000
	Operatories	0.417	0.080	5.211	0.000
	Delegation	0.102	0.048	2.095	0.038
	R-square=0.812, F=161.266, N=154				
Regression 2	Constant	6.365	0.512	12.431	0.000
	Dentists Hours	0.332	0.070	4.773	0.000
	Auxiliary Hours	0.434	0.060	7.174	0.000
	Operatories	0.410	0.077	5.318	0.000
	Index-Simple	0.005	0.001	3.680	0.000
	R-square=0.823, F=173.107, N=154				
Regression 3	Constant	6.358	0.533	11.926	0.000
	Dentists Hours	0.300	0.071	4.230	0.000
	Auxiliary Hours	0.469	0.061	7.639	0.000
	Operatories	0.437	0.079	5.545	0.000
	Index-Weighted	0.002	0.001	2.060	0.041
	R-square=0.812, F=160.585, N=154				

Table 13: Estimated Modified Cobb-Douglas Production Function, Dependent Variable =Value-Added

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	5.982	0.546	10.963	0.000
	Dentists Hours	0.299	0.074	4.039	0.000
	Auxiliary Hours	0.499	0.062	8.058	0.000
	Operatories	0.418	0.083	5.008	0.000
	Delegation	0.102	0.050	2.018	0.045
	R-square=0.801, F=149.474, N=154				
Regression 2	Constant	6.211	0.535	11.615	0.000
	Dentists Hours	0.327	0.073	4.498	0.000
	Auxiliary Hours	0.440	0.063	6.966	0.000
	Operatories	0.411	0.081	5.100	0.000
	Index-Simple	0.005	0.001	3.505	0.001
	R-square=0.823, F=159.494, N=154				
Regression 3	Constant	6.206	0.555	11.178	0.000
	Dentists Hours	0.295	0.074	3.993	0.000
	Auxiliary Hours	0.475	0.064	7.424	0.000
	Operatories	0.438	0.082	5.329	0.000
	Index-Weighted	0.002	0.001	1.985	0.049
	R-square=0.800, F=149.310 N=154				

Table 14: Estimated Modified Cobb-Douglas Production Function, Dependent Variable =Visits

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	1.496	0.594	2.519	0.013
	Dentists Hours	0.414	0.081	5.142	0.000
	Auxiliary Hours	0.341	0.067	5.063	0.000
	Operatories	0.432	0.091	4.764	0.000
	Delegation	0.161	0.055	2.927	0.004
	R-square=0.756, F=115.237, N=154				
Regression 2	Constant	1.771	0.588	3.010	0.003
	Dentists Hours	0.443	0.080	5.534	0.000
	Auxiliary Hours	0.277	0.069	3.980	0.000
	Operatories	0.438	0.089	4.943	0.000
	Index-Simple	0.006	0.001	3.685	0.000
	R-square=0.763, F=120.087, N=154				
Regression 3	Constant	1.831	0.607	3.017	0.003
	Dentists Hours	0.408	0.081	5.048	0.000
	Auxiliary Hours	0.306	0.070	4.380	0.000
	Operatories	0.465	0.090	5.185	0.000
	Index-Weighted	0.003	0.001	2.693	0.008
	R-square=0.754, F=113.963, N=154				

There are several important points to consider regarding the regression estimates presented in Tables 9-14. First, the production function specifications (both Cobb-Douglas and modified Cobb-Douglas) seem to fit the empirical observations of the sampled general dental practices very well—the R-squares of all estimated functions were consistently high and statistically significant. Second, all input coefficients were consistent, positive and significant. Third, the sum of the estimated input coefficients with and without the delegation exceed the value of one (and the difference is statistically significant) indicating economies of scale. Fourth, the estimated coefficients of all three delegation measures (qualitative, index-simple and index-weighted) are consistent, positive, and significant and they do not seem to affect the values of the estimated input coefficients.

Effects of Delegation on Output

The regression results presented in Tables 12-14 indicated that delegation (calculated and represented in three ways) has a positive impact on gross billings, value-added, and visits. Using the coefficients displayed in Tables 12-14, the estimates of the impact of delegation are provided at various levels of delegation in Tables 15-17 for gross billings and in Tables 18-20 for visits. (Similar tables illustrating the impact of delegation on value-added were generated but not included.)

In Table 15, the impact of delegation—measured by the qualitative variable created using Q20—on gross billings is 10.74%. That is, on average, gross billings of those who said "Yes" to Q20 were $70,168 higher than for those who said "No." It is important to acknowledge that Question 20 was generic in that dentists may have responded based on different personal definitions of "expanded function auxiliaries."

Table 15: Impact of Delegation on Gross Billings Using the Qualitative Variable Delegation Measure

Level of Delegation	Gross Billings	Percent Change in Gross Billings
Zero (delegation=no=0)	$653,436	N/A
100% (delegation=yes=1)	$723,604	10.74%

The impact of delegation—measured by the simple index created using Q23—on gross billings is shown in Table 16. For example, the gross billings of those who had a delegation index of 40% were on average 22.14% higher than those who had a delegation index of 0%—in dollar terms, this is a difference of $132,549. Table 17 shows similar results using the delegation weighted index. (Note that the estimated impacts are lower because this measure takes into account the mix of services as a percentage of gross billings. Thus, this index is sensitive to case-mix of the practices. In other words, if a practice is more inclined toward procedures where delegation cannot occur, then the index would be lower.)

Table 16: Impact of Delegation on Gross Billings Using the Simple Index Delegation Measure

Level of Delegation	Gross Billings	Percent Change in Gross Billings
Zero	$598,679	N/A
20%	$661,642	10.52%
40%	$731,228	22.14%
60%	$808,131	34.99%
80%	$893,123	49.18%
100%	$987,054	64.87%

Table 17: Impact of Delegation on Gross Billings Using the Weighted Index Delegation Measure

Level of Delegation	Gross Billings	Percent Change in Gross Billings
Zero	$663,292	N/A
20%	$690,361	4.08%
40%	$718,535	8.33%
60%	$747,859	12.75%
80%	$778,380	17.35%
100%	$810,146	22.14%

Again, the results described above indicate that the delegation of activities/ procedures to expanded duty dental auxiliaries have a positive and significant impact on the gross billings of a general dental practice. The differences in the magnitude of the impact may be an indication of the importance of the service-mix in a dental practice.

Tables 18-20 show the impact of various levels of delegation on dental visits. Similar to gross billings analysis, these tables illustrate the potential impact of various degrees of delegation on the absolute number of dental visits and the percent increase as the level of delegation increases. Once more, the impact of delegation is positive and significant. For example, using the simple index measure of delegation, Table 19 shows that the number of annual visits of those who had a delegation index of 40% were on average 27.14% higher than those who had a delegation index of 0%—or a difference of 996 visits.

Table 18: Impact of Delegation on Dental Visits Using the Qualitative Variable Delegation Measure

Level of Delegation	Dental Visits	Percent Change in Dental Visits
Zero (delegation=no=0)	3,899	N/A
100% (delegation=yes=1)	4,580	17.47%

Table 19: Impact of Delegation on Dental Visits Using the Simple Index Delegation Measure

Level of Delegation	Dental Visits	Percent Change in Dental Visits
Zero	3,670	N/A
20%	4,139	12.78%
40%	4,666	27.14%
60%	5,261	43.35%
80%	5,931	61.61%
100%	6,688	82.23%

Table 20: Impact of Delegation on Dental Visits Using the Weighted Index Delegation Measure

Level of Delegation	Dental Visits	Percent Change in Dental Visits
Zero	4,004	N/A
20%	4,251	6.17%
40%	4,514	12.74%
60%	4,793	19.71%
80%	5,090	27.12%
100%	5,405	34.99%

Clinical (Technical) Efficiency Analyses

Using Data Envelopment Analysis (DEA), we estimated the technical efficiency of each of the 154 dental practices relative to other practices in the sample, based on dental visits, gross billings, and value-added as alternative measures of output. We used the same set of inputs employed in the Cobb-Douglas production function specification and generated efficiency scores for each dental practice in the sample. One important feature of DEA is that it yields a measure of the technical efficiency of each dental practice relative to the most efficient practices in the sample. These efficiency scores potentially range from zero to one. Rather than invoking some hypothetical notion of efficiency, DEA compares the observed performance of each dental practice to the observed performance of other practices in the sample.

Table 21 gives the distribution of efficiency scores across the 154 private general practices based on gross billings, visits, and value-added. As can be seen, most practices were found to be very efficient based on gross billings—but that same distribution of efficiency scores does not hold when efficiency is based on visits or value-added. While efficiency scores vary based on the output measure used, they are positively correlated as shown in Table 22.

Table 21: Distribution of Private General Practice Efficiency Scores on Gross Billings, Visits and Value-Added

Efficiency Scores	Gross Billings (mean score=0.833)	Visits (mean score= 0.600)	Value-Added (mean score=0.670)
1.00	42	25	20
0.90 – 0.99	19	4	4
0.80 – 0.89	28	4	14
0.70 – 0.79	34	11	25
0.60 – 0.69	20	16	29
0.50 – 0.59	10	29	33
0.40 – 0.49	0	38	18
Less than 0.40	1	27	11
All	154	154	154

Table 22: Correlation Matrix of Gross Billings, Visits and Value-Added

	Gross Billings	Visits	Value-Added
Gross Billings	1.000	-	-
Visits	0.630	1.000	-
Value-Added	0.869	0.605	1.000

EFFECTS OF DELEGATION ON EFFICIENCY

As shown in Table 21, there is marked variation in efficiency scores. Clearly, there are many factors that can be associated with the variation in efficiency scores: (1) practitioner factors[1] such as age, experience, gender, educational background, specialty, etc.; (2) structural factors such as practice size, extent of delegation or expanded duties, office layout, etc.; and (3) market factors such as urban/rural setting, patient age-mix, degree of local competition, etc. Thus, once the efficiency score of each dental practice is generated, a second-stage regression analysis is used to explore the sources of efficiency score differences. This second-stage analysis is particularly useful in measuring the effects of delegation as well as other dimensions associated with a dental practice, including location, staff and patient characteristics.

Table 23 shows the results of the second-stage regression analysis where the dependent variable is the index of efficiency based on gross billings. It should be noted that the explanatory power of these regressions, as measured by the R-square, is much lower than it was for the Cobb-Douglas or modified Cobb-Douglas production functions. However, the second-stage DEA analysis of efficiency scores usually have a low goodness of fit statistics (i.e., R-square).[2]

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[1] Since the analysis is at the practice-level, practitioner factors were not used as they are only available for the dentist filling out the survey and not for all dentists in the practice. The one exception is the use of the variable capturing whether the responding dentist had taken any CE courses focusing on the use of expanded functions for auxiliaries ("Training").

[2] The reason for this is that bulk of the variation in the output (rather than the efficiency score) is explained by systematic factors like variation in the input quantities. In that sense, the DEA efficiency score is itself like the "residual" from a regression. The total variation in the dependent variable of a regression model is due to variation in independent variables and noise. In efficiency analysis, it is generally found that systematic variation is low relative to random factors that include both intrinsic efficiency (or ability not measured by environmental factors) and random noise. It is important to recall in this context that in sociological analysis with cross section data, R-square is usually very low.

Table 23: Estimated Effects of Delegation and Training on Efficiency Based on Gross Billings, Dependent Variable = Index of Efficiency in Gross Billings

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	0.992	0.155	6.409	0.000
	Training	0.064	0.041	1.563	0.120
	% White	-0.125	0.183	-0.684	0.495
	% No-show	-0.005	0.002	-2.138	0.034
	% of gross from uninsured patients	-0.002	0.001	-2.290	0.023
	% with BA degree	-0.056	0.240	-0.234	0.815
	Dentist/square mile	-0.002	0.008	-0.219	0.827
	Per capita income	0.000000608	0.000	0.185	0.854
	Delegation	0.033	0.025	1.324	0.187
	R-square=0.092, F=1.892, N=154				
Regression 2	Constant	0.959	0.154	6.228	0.000
	Training	0.059	0.040	1.467	0.144
	% White	-0.116	0.181	-0.641	0.523
	% No-show	-0.005	0.002	-2.334	0.021
	% of gross from uninsured patients	-0.001	0.001	-2.042	0.043
	% with BA degree	-0.065	0.236	-0.276	0.783
	Dentist/square mile	-0.001	0.008	-0.111	0.912
	Per capita income	0.000000710	0.000	0.218	0.828
	Index-Simple	0.001	0.001	2.139	0.034
	R-square=0.109, F=2.213, N=154				
Regression 3	Constant	0.990	0.153	6.470	0.000
	Training	0.056	0.041	1.353	0.178
	% White	-0.126	0.182	-0.696	0.487
	% No-show	-0.006	0.002	-2.391	0.018
	% of gross from uninsured patients	-0.002	0.001	-2.111	0.037
	% with BA degree	-0.054	0.237	-0.228	0.820
	Dentist/square mile	-0.003	0.008	-0.340	0.734
	Per capita income	0.000000760	0.000	0.231	0.817
	Index-Weighted	0.001	0.001	1.694	0.092
	R-square=0.099, F=1.981, N=154				

In Table 23, the majority of the independent variables controlling for patient and market characteristics (see variable list and definitions on page 14) were not statistically significant at conventional levels. As shown, demographic characteristics of the population at the zip code level of the practice location (i.e., race captured by "% white," education captured by "% with BA degree," and income captured by "per capita income") were not statistically significant.

Two practice level variables that were significant were the estimated percentage of all scheduled appointments for which the patient did not appear (% No-show) and the estimated percent of gross billings received from uninsured patients (% of gross from uninsured patients). Both variables had negative coefficients, indicating an inverse relationship with efficiency scores.

With respect to delegation as an independent variable, in Table 23, Regression 1, delegation measured by the qualitative variable is not statistically significant at conventional levels. In Regression 2, delegation measured by the simple index is statistically significant and has a positive coefficient. In Regression 3, delegation measured by the weighted index is statistically significant but only at a 10% level.

Using the coefficients from Regression 2 in Table 23 (the regression where the delegation measure had the highest statistical significance), the estimates of the impact of delegation—measured by the simple index created using Q23—on efficiency scores are provided at various levels of delegation in Table 24. For example, the efficiency scores of those who had a delegation index of 80% were on average 14.62% higher than those who had a delegation index of 0%—i.e., increasing delegation from 0% to 80% would potentially increase the efficiency score from 0.788 to 0.903. Table 26 shows similar results using the delegation weighted index.

Table 24: Impact of Delegation on Efficiency with Respect to Gross Billings, Using the Simple Index Delegation Measure

Level of Delegation	Efficiency Score	Percent Change in Efficiency Score
Zero	0.788	N/A
20%	0.817	3.65%
40%	0.846	7.31%
60%	0.874	10.96%
80%	0.903	14.62%
100%	0.932	18.27%

Next, the same regressions were run except this time the dependent variable is the index of efficiency based on visits instead of gross billings. The results are shown in Table 25. Here, none of the independent variables controlling for patient and market characteristics were statistically significant at conventional levels. "Training," the variable capturing whether dentists had taken any CE courses focusing on the use of expanded functions for auxiliaries, was most significant in Regression 1 and only significant at the 10% level in Regression 3. With respect to delegation, two of the three measures of delegation were statistically significant in Table 25. Clearly, delegation seems to have some effect on efficiency with respect to patient visits. Statistical significance of the effect, as measured by the t-value, is highest when the weighted index of delegation is used.

Table 25: Estimated Effects of Delegation and Training on Efficiency Based on Patient Visits, Dependent Variable = Index of Efficiency in Patient Visits

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	0.673	0.238	2.824	0.005
	Training	0.120	0.063	1.919	0.057
	% White	-0.025	0.282	-0.088	0.930
	% No-show	-0.003	0.004	-0.930	0.354
	% of gross from uninsured patients	-0.001	0.001	-1.099	0.273
	% with BA degree	-0.459	0.369	-1.243	0.216
	Dentist/square mile	-0.014	0.013	-1.050	0.295
	Per capita income	0.00000288	0.000	0.567	0.571
	Delegation	0.075	0.038	1.960	0.052
	R-square=0.097, F=1.942, N=154				
Regression 2	Constant	0.696	0.241	2.886	0.004
	Training	0.120	0.063	1.898	0.060
	% White	-0.048	0.283	-0.168	0.867
	% No-show	-0.004	0.004	-1.082	0.281
	% of gross from uninsured patients	-0.001	0.001	-0.985	0.326
	% with BA degree	-0.405	0.369	-1.097	0.274
	Dentist/square mile	-0.015	0.013	-1.146	0.254
	Per capita income	0.00000253	0.000	0.497	0.620
	Index-Simple	0.001	0.001	1.399	0.164
	R-square=0.085, F=1.688, N=154				
Regression 3	Constant	0.681	0.236	2.890	0.004
	Training	0.105	0.063	1.660	0.099
	% White				
	% No-show	-0.005	0.004	-1.275	0.204
	% of gross from uninsured patients	-0.001	0.001	-0.889	0.376
	% with BA degree	-0.441	0.366	-1.206	0.230
	Dentist/square mile	-0.016	0.013	-1.257	0.211
	Per capita income	0.00000309	0.000	0.610	0.543
	Index-Weighted	0.002	0.001	2.206	0.029
	R-square=0.103, F=2.081, N=154				

Using the coefficients from Regression 3 in Table 25 (i.e., where the measure of delegation is the weighted index), the estimates of the impact of delegation at various levels of delegation were calculated and are displayed in Table 26. For example, the efficiency scores of those who had a weighted delegation index of 80% were on average 28.9% higher than those who had a delegation index of 0%—i.e., increasing delegation from 0% to 80% would potentially increase the efficiency score from 0.554 to 0.714.

Table 26: Impact of Delegation on Efficiency with Respect to Patient Visits, Using the Weighted Index Delegation Measure

Level of Delegation	Efficiency Score	Percent Change in Efficiency Score
Zero	0.554	N/A
20%	0.594	7.2%
40%	0.634	14.4%
60%	0.674	21.7%
80%	0.714	28.9%
100%	0.754	36.1%

EFFECTS OF DELEGATION ON PRACTICE NET INCOME

An ad hoc regression model was used to assess the impact delegating expanded duties to dental auxiliaries on the net income of a general practice. (Note that here the dependent variable is the practice net income and not efficiency scores as in the previous section.) The results are shown in table 27.

While the explanatory power of these regressions, as measured by the R-square, is low, all three regressions are statistically significant as measured by the F-value. The results indicate that, controlling for a number of patient and practice characteristics including efficiency in gross billings, delegation is positively and substantially associated with the net income of general dental practices in Colorado.

Aside from delegation and efficiency in gross billings, only one other independent variable was statistically significant in all three regressions: "% No-show" (the estimated percentage of all scheduled appointments for which the patient did not appear). One would expect the sign of this variable to be negative, all else being equal. However, one plausible explanation is if practices with high percentage of no shows tend to overbook appointments, then there would be no slack in timing and this could account for the positive sign of the coefficient.

Table 27: Estimated Effects of Delegation on Net Income

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	-450348	293404	-1.535	0.127
	Training	-30679	68465	-0.448	0.655
	Efficiency in gross billings	318192	143544	2.217	0.028
	% White	309731	303814	1.019	0.310
	% No-show	14643	3976	3.683	0.000
	% of gross from uninsured patients	555	1197	0.464	0.644
	% with BA degree	-288399	398731	-0.723	0.471
	Dentist/square mile	9760	14072	0.694	0.489
	Per capita income	2.482	5.486	0.453	0.652
	Delegation	126651	41154	3.078	0.002
	R-square=0.156, F=2.967, N=154				
Regression 2	Constant	-506512	288524	-1.756	0.081
	Training	-40600	67267	-0.604	0.547
	Efficiency in gross billings	311060	140807	2.209	0.029
	% White	316006	297504	1.062	0.290
	% No-show	13241	3905	3.391	0.001
	% of gross from uninsured patients	1029	1185	0.868	0.387
	% with BA degree	-272914	388890	-0.702	0.484
	Dentist/square mile	11073	13783	0.803	0.423
	Per capita income	2.475	5.374	0.461	0.646
	Index-Simple	4095	1039	3.943	0.000
	R-square=0.189, F=3.718, N=154				
Regression 3	Constant	-440477	287610	-1.532	0.128
	Training	-58868	68213	-0.863	0.390
	Efficiency in gross billings	311250	141531	2.199	0.029
	% White	298439	298721	0.999	0.319
	% No-show	12342	3949	3.125	0.002
	% of gross from uninsured patients	966	1190	0.812	0.418
	% with BA degree	-267727	390944	-0.685	0.495
	Dentist/square mile	5777	13714	0.421	0.674
	Per capita income	2.928	5.412	0.541	0.589
	Index-Weighted	3320	889	3.736	0.000
	R-square=0.180, F=3.521, N=154				

Using these regression results we calculated the magnitude of the delegation impact on practice net income at various level of delegation. Tables 28-30 show the results. In Table 28, the impact of delegation—measured by the qualitative variable created using Q20—on practice net income is 62.51%. That is, on average, practice net income of those who said “Yes” to Q20 was estimated to be $126,651 higher than for those who said “No.”

Table 28: Impact of Delegation on Practice Net Income Using the Qualitative Variable Delegation Measure

Level of Delegation	Net Income	Percent Change in Net Income
Zero (delegation=no=0)	$202,612	N/A
100% (delegation=yes=1)	$329,263	62.51%

The estimated impact of delegation—measured by the simple index created using Q23—on practice net income is shown in Table 29. For example, the practice net income of those who had a delegation index of 40% were on average 106.02% higher than those who had a delegation index of 0%—in dollar terms, this is a difference of $163,820. Table 30 shows similar results using the delegation weighted index. (Note that the estimated impacts are lower because this measure takes into account the mix of services as a percentage of gross billings. Thus, this index is sensitive to case-mix of the practices. In other words, if a practice is more inclined toward procedures where delegation cannot occur, then the index would be lower.)

Table 29: Impact of Delegation on Practice Net Income Using the Simple Index Delegation Measure

Level of Delegation	Net Income	Percent Change in Net Income
Zero	$154,504	N/A
20%	$236,414	53.01%
40%	$318,324	106.02%
60%	$400,234	159.04%
80%	$482,144	212.06%
100%	$564,054	265.07%

Table 30: Impact of Delegation on Practice Net Income Using the Weighted Index Delegation Measure

Level of Delegation	Net Income	Percent Change in Net Income
Zero	$203,633	N/A
20%	$269,831	32.64%
40%	$336,229	65.44%
60%	$402,626	97.92%
80%	$469,024	130.55%
100%	$535,422	163.19%

Table 31 presents the results of the ad hoc regression model attempting to assess the effects of delegation on the net income per dentist hour. However, of the three regressions only delegation measured by the simple index is statistically significant. These results suggest that the effect of delegation on net income per dentist hour, controlling for a number of patient and practice characteristics including efficiency in gross billings, is not as clear cut as the delegation effects on practice net income.

Table 31: Estimated Effects of Delegation on Net Income per Dentist Hour

	Variable	Coefficient	Std. Error	t-value	Prob > |t|
Regression 1	Constant	-91.859	72.041	-1.275	0.204
	Training	-8.661	16.811	-0.515	0.607
	Efficiency in gross billings	151.067	35.245	4.286	0.000
	% White	85.502	74.597	1.146	0.254
	% No-Show	0.464	0.976	0.475	0.635
	% of gross from uninsured patients	0.410	0.294	1.395	0.165
	% with BA degree	89.384	97.903	0.913	0.363
	Dentist/square mile	1.291	3.455	0.374	0.709
	Per capita income	-0.001	0.001	-0.992	0.323
	Delegation	11.899	10.105	1.178	0.241
	R-square=0.145, F=2.715, N=154				
Regression 2	Constant	-107.988	71.246	-1.516	0.132
	Training	-10.700	16.610	-0.644	0.520
	Efficiency in gross billings	148.986	34.770	4.285	0.000
	% White	91.538	73.463	1.246	0.215
	% No-Show	0.280	0.964	0.291	0.772
	% of gross from uninsured patients	0.489	0.293	1.672	0.097
	% with BA degree	81.788	96.029	0.852	0.396
	Dentist/square mile	1.847	3.403	0.543	0.588
	Per capita income	-0.001	0.001	-0.956	0.341
	Index-Simple	0.598	0.256	2.333	0.021
	R-square=0.168, F=3.237, N=154				
Regression 3	Constant	-91.247	71.470	-1.277	0.204
	Training	-11.397	16.951	-0.672	0.502
	Efficiency in gross billings	150.355	35.170	4.275	0.000
	% White	84.634	74.231	1.140	0.256
	% No-Show	0.243	0.981	0.248	0.804
	% of gross from uninsured patients	0.450	0.296	1.522	0.130
	% with BA degree	90.953	97.148	0.936	0.351
	Dentist/square mile	0.924	3.408	0.271	0.787
	Per capita income	-0.001	0.001	-0.960	0.339
	Index-Weighted	0.319	0.221	1.446	0.150
	R-square=0.149, F=2.805, N=154				

DENTAL PRACTICE ANALYSES

This project included a customized practice analysis for each of the 81 respondents who also provided detailed production information from their practice management systems. An example of the type of analysis is provided in Appendix C. It should be noted that for confidentiality reasons this profile is not one of the 81 responding practices. In fact, the individualized data presented in this profile are fictitious. Each customized profile includes seven major components:

(1) Basic descriptive practice characteristics (e.g., solo, incorporated practice with 5 operatories);

(2) Input and output measures considered, sample size, the estimated efficiency score of the practice in terms of gross billings, and the distribution of efficiency scores of practices in the sample;

(3) The quantity of inputs **used** in the practice, the quantity of inputs **needed** by a fully-efficient practice (with DEA score = 1.00) to produce the reported gross billings, and the **potential** or maximum gross billings that could be produced with no more inputs than the practice currently uses;

(4) The incremental and average estimated productivity of the practice's major inputs (e.g., dentist hours, dental auxiliary hours, operatories);

(5) Whether the practice delegates expanded duties, the level of delegation across several specific procedures/activities, and the distribution of these measures across practices in the sample;

(6) The contribution of delegation to gross billings of an average practice at various levels of delegation; and

(7) The output of the practice (measured by gross billings, total number of visits, and value-added) per dentist hour, and the distribution of this figure across practices in the sample.

Discussion

DATA LIMITATIONS

This report is based on a sample of 154 private general dental practices located in the state of Colorado. The sample was selected from a previous study of expanded function dental auxiliaries. As such, it may not be perfectly representative of Colorado general practices. Sampled practices were selected to represent low, medium and high levels of delegation based on the classification of the previous study. Caution must be used in generalizing the results to all Colorado private general dentists or to general dentists in other states that allow the delegation of expanded duties to dental hygienists and assistants.

Level of Delegation

This study sample had 98 practices (64%) that reported delegating expanded services to dental hygienists and chairside assistants. This is a substantial number, especially considering that another 11% delegated services in the past. Thus, 75% of dentists, the great majority, had experience using expanded duty auxiliaries. The practices that stopped delegating services were not asked to give a reason for their decision, but this issue merits further investigation.

As expected, practices that did and did not delegate were very different. The delegating practices were larger (operatories and square feet) and had higher annual hours worked by dentists, dental hygienists, and chairside assistants. The hours worked by other staff were also higher among delegating practices, but the difference was not statistically significant. With a much larger operation, the delegating practices generated much larger gross billings, net income, and patient visits. Indeed, the average difference in net income between the two groups of practices was over $100,000.

The specific expanded services delegated are mainly associated with restorative and prosthetic services. For example, about 35% of amalgam placement and finishing procedures were delegated to auxiliary staff (among about 50% of all practices). An even larger percentage of practices had auxiliary staff placing and adjusting temporary crowns and bridges (Table 6). Approximately 43% of practices had auxiliary staff cementing and adjusting permanent crowns and bridges. Likewise, a large percentage of tasks associated with removable dentures were delegated to auxiliary staff. Examples include final RPD impressions (48.4%) and adjusting RPDs (36.7%).

Of particular interest is the fact that many practices delegated critical steps in the construction of fixed and removable prostheses. These include final impressions for crowns and partial and full dentures and the cementation and adjustment of permanent crowns and bridges. This suggests that properly trained and supervised auxiliaries can provide these services effectively and at lower cost to the practice. Of course, this is conjecture, and more detailed studies are needed to assess the impact of delegation on the cost and quality of care.

The distribution of practices by the percent of services delegated indicated that only a small percentage of practices delegated more than 55% of services. Indeed, the great majority of practices delegated less than 35% percent of services. The obvious question is why don’t dentists delegate more services? Certainly, dentists appear to have a major financial incentive to delegate more services, but there must be other important barriers that need to be investigated.

The simple index appears to give a better estimate of the level of delegation within practices because it reflects the many small restorative and prosthetic tasks assigned to expanded duty chairside assistants. In contrast, the weighted index focuses on a few services associated with higher value restorative and prosthetic care.

Productivity and Economies of Scale

To assess the effects of delegation on productivity in general dental practices, we estimated a series of Cobb-Douglas production functions using gross billings, number of visits and value-added as output measures. The production function regressions clearly indicate the important contribution of all the inputs (i.e., dentist hours, dental auxiliary hours and number of operatories) in generating higher gross billings, patient visits and value-added. All coefficients were statistically significant. Many other studies have reported the same associations. In addition, these estimates indicate statistically significant economies of scale for the sample practices (the sum of all input coefficients is greater than one, indicating that equal percentage increases in all inputs tend to increase output of the practice by a somewhat larger percentage). These production function estimates are the foundation for establishing the effects of delegation.

Clinical Efficiency

DEA is a powerful tool to compare the relative efficiency of general dental practices. There was considerable variation among dental practice efficiency scores. The average technical efficiency score of the sampled practices was 0.833 for gross billings. Although detailed results were not presented, it is important to note that upon conducting individual practice analyses, 42 of the 154 practices were identified as "frontier" or "model" practices, with an efficiency score of one. The analyses indicated that the current output of some dental practices could be produced with fewer dentist and auxiliary hours and lower lab costs by the technically efficient practices. Such information should be useful to dental practice management as it seeks to increase clinical efficiency. Estimating the efficiency scores of the sampled practices was also the first step in assessing the effects of delegation.

Effects of Delegation

The main objectives of this study were to assess the effects of delegation on dental output and efficiency of general dental practices in Colorado. The estimates from the modified Cobb-Douglas regressions clearly indicate that delegation in general, as well as delegation of specific procedures/activities to dental hygienists and assistants, has an important effect on gross billings, patient visits and value-added. All estimated coefficients are statistically significant at conventional levels of significance (Tables 12-14). Most importantly, the effects of delegation are substantive and are positively related with the level of delegation (Tables 16-17). These results are broader and more significant than the few reported in the literature (Milgrom et al, 1983).

Similarly, delegating specific procedures/activities to dental hygienists and assistants has an important effect on the clinical (technical) efficiency of a general dental practice based on gross billings. For example, the efficiency scores of those with a simple delegation index of 80% were on average 14.62% higher than those with a simple delegation index of 0%.

One of the most powerful effects of delegation seems to be on practice net income. Unlike previous studies (Milgrom et al, 1983), the effects of delegation on practice net income is substantial.

A critical unanswered issue is: Is delegation good for every dentist? There is no simple answer to this question, because it is at least possible that practices that delegated more tasks also did many other things differently. Thus, delegation per se may be only one reason for greater output. This study cannot answer this question definitively, but the differences between the two groups of practices may transcend delegation (e.g., the delegating dentists may be better managers, have higher income objectives). An interesting extension of this study would be to assess the potential differences in the quality of the procedures/activities performed by expanded duty auxiliaries and dentists, thus expanding on the work done by Bergner et al (1983).

Policy Implications

In terms of policy implications, this study suggests that private general dental practices can substantially increase gross billings, patient visits, value-added, efficiency and practice net income with the delegation of more duties to auxiliaries. This is an important issue as the nation addresses the problem of access disparities.

A major challenge for dental education and the profession is to provide clinical training to students, residents, and community dentists on the effective use of expanded duty dental auxiliaries—assuming sufficient quantity demanded of dental care services. Currently, few dental schools have special courses or offer clinical experiences focused on this issue. In part, this is because of the declining resources available to public dental schools, as state and federal support for health professional education wanes.

From both a professional and community perspective, it may be more effective and less costly to channel additional resources into training dentists to practice more efficiently than to simply increase the number of dentists. Yet, current trends are moving in the opposite direction. This is an important health policy issue that warrants immediate but careful attention.

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Appendix A

ADA®

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Chicago, Illinois 60611
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2006 Survey of Expanded Duties for Dental Auxiliaries

Please circle the number corresponding to the most appropriate response or fill in the blank. Please do not report ranges.

If your entire primary practice consists of several office locations, please answer the practice questions for your **largest practice** and/or the one in which you **spend most of your time**.

Individual Dentist Questions

1. In what year did YOU **start/join** your **primary practice**? .... ________ year

2. Have you graduated from either a General Practice Residency (GPR) or Advanced Education in General Dentistry (AEGD) program?
   - a. Yes, a GPR program 1
   - b. Yes, an AEGD program 2
   - c. No 3

3. Please answer the following about the time you spent in your primary practice during **2005**.
   - a. Total number of **weeks** worked (Do not include vacation.) .... ________
   - b. Average number of **hours per week** spent in the practice .... ________

4. Please estimate the total dollar amount of free or discounted charitable care **you personally** provided to institutionalized individuals, elderly patients, low-income individuals, or any other underserved populations during **2005**. Do not include accounts receivable, bad debt, or care provided as a professional courtesy. (If none, enter zero.) .... $________

5. Have you taken any continuing education courses focusing on the use of expanded functions for auxiliaries in the **past three years**?
   - Yes 1
   - No 2

Primary Practice Questions

6. What was your employment situation in **2005**?
   - a. **The practice was:**
     1. incorporated 1
     2. unincorporated 2
   - b. **You were:**
     1. a sole proprietor (i.e., the only **owner**) 1
     2. a partner (i.e., one of two or more **owners**) 2
     3. an employee (on a salary, commission, percentage or associate basis) 3
     4. an independent contractor 4

7a. Do you provide dental services at more than one physical location?
   - Yes 1
   - No 2

7b. Is your practice part of a larger company that delivers dental care in more than one location (e.g. a franchise)?
   - Yes 1
   - No (Skip to Question 8) 2

7c. Does the owning company use: (Circle all that apply).
   1. a directed pricing system? 1
   2. a directed accounting system? 2
   3. a company-wide policy on delegation? 3

8. In the **primary practice location** during **2005**, what was the total:
   - a. square feet of office space? .... ________
   - b. number of fully equipped operatories? ... ________

9. Please indicate the **total number** of general practitioners and specialists in your primary practice location. **Please include yourself**.
   - a. General practitioners .... ________
   - b. Specialists .... ________

10. Please indicate the total number of full-time and part-time **non-dentist staff** in your primary practice location.
   - a. Number of full-time staff (32 hours or more per week) .... ________
   - b. Number of part-time staff (less than 32 hours per week) .... ________

11. What was the average scheduled length of an appointment for the **primary practice location** in **2005**? .... ________ minutes

12. For the **primary practice location**, please estimate the percentage of all scheduled appointments for which the patient did not appear ("no-shows") during **2005**? .... ________%

13. For the **primary practice location** during **2005**, how long did the average patient of record and the average new patient have to **wait**:

	Patient of Record	New Patient
a. for the **initial appointment** of a series (excluding emergency cases)?	________ days	________ days
b. to see a dentist **after** the patient arrived for a **scheduled** appointment?	________ minutes	________ minutes

14. Please indicate the average number of visits **per week** for the following during **2005**.

a. Visits per week treated by all dentists in your practice *excluding hygienist visits* .... ________

b. Emergency and walk-in visits per week treated by all dentists in the practice ..... ________

c. Visits per week treated *by all hygienists* in your practice .... ________ visits/week

15. **In your best estimate,** what percentage of **ALL** the patients who visited the **primary practice location** in **2005**:

a. were of the following ages?

Less than five years of age .... ________%
5 to 17 years of age .... ________%
18 to 34 years of age .... ________%
35 to 54 years of age .... ________%
55 to 64 years of age .... ________%
65 years of age and older .... ________%
total 100%

b. had family incomes in the following categories?

Under $15,000 ....________%
$15,000-$34,999 ....________%
$35,000-$69,999 ....________%
$70,000-$99,999 ....________%
$100,000 and above ....________%
total 100%

Practice Income Questions

16. **PRACTICE ANNUAL GROSS BILLINGS**: In the **primary practice location**, what was the total amount of fees charged for dental care in **2005** (**annual gross billings**)? .... $________

17. **PRACTICE GROSS RECEIPTS**: In the **primary practice location**, what were the total **gross receipts actually collected** in **2005**? (If you do not extend credit, this figure may be the same as in Question 16.)............................ $________

18. **PERCENTAGE OF GROSS RECEIPTS**: Of the **gross receipts** collected in **2005**, what percentage was received: (If none, enter zero.)

a. from *uninsured* patients? .... ________%
b. from private insurance:
as direct payment from *insured* patients (i.e., **patient co-pay**)? .... ________%
as direct payment from private insurance carriers (i.e., PPOs and indemnity plans)? .... ________%
as direct payment from capitation plans? .... ________%
c. as payment from government programs, (e.g., Medicare, Medicaid, or other public insurance)?........................ ________%
d. from other sources of payment?........... ________%
total 100 %

19a. **TOTAL PRACTICE EXPENSES**: Please indicate the annual professional expenses for your **primary practice location** in 2005? .... $________

19b. For each of the following items below, please indicate the **annual professional expenses** for your **primary practice location** in **2005**. (If no expenses were incurred, please enter zero for each.)

a. Commercial dental laboratory charges . $________
b. Dental supplies .... $________
c. Yearly rent .... $________
d. Yearly mortgage (including interest) ..... $________
e. Total salaries/wages of non-dentist staff (including fringe benefits)..................... $________

Delegation and Staffing Questions

20. Do you currently use, or at one time used, expanded function auxiliaries in your **primary practice location**?

Yes, currently use 1
Yes, once used but have discontinued........................... 2
No, never used.. 3

If you are **not** currently using expanded function auxiliaries, skip to Question 22. Otherwise, please continue with Question 21a.

21a. In what year did **YOU** begin using expanded function auxiliaries?.................................... ________ year

21b. **In the past three years** would you say that your **primary practice's** use of expanded function auxiliaries has:

1. increased more than 50%?.................................. 1
2. increased 0% to 50%?.. 2
3. remained the same?... 3
4. decreased 0% to 50%?.. 4
5. decreased more than 50%?.................................. 5

21c. If your practice is owned by a company, is the use of expanded function auxiliaries established:

1. by the company? 1
2. at the practice level?.. 2
3. by the individual dentists in the practice?.............. 3
4. not applicable.. 4
5. other, please specify ________________________

22. If you are working in a multi-dentist practice, are all dentists in this practice:

	Yes	No	Not Applicable
a. delegating the same procedures?	1	2	3
b. delegating procedures approximately the same percentage of time?	1	2	3

23. Of all the times the following procedures are performed in your **primary practice location**, approximately what percentage are delegated to chairside assistants or dental hygienists? If the procedure is not performed or not delegated, please circle the appropriate number for each procedure.

	Not Performed	Not Delegated	% of Procedure
Diagnostic/Preventive/Adjunctive			
a. Take PA or BW radiographs	1	2	______
b. Take panoramic radiographs	1	2	______
c. Provide prophylaxis	1	2	______
d. Place occlusal sealant(s)	1	2	______
e. Administer topical fluoride	1	2	______
f. Apply fluoride varnish	1	2	______
g. Take and pour alginate impressions	1	2	______
Operative, Primary and Permanent Teeth			
a. Place wedge/matrix for amalgam	1	2	______
b. Place/finish amalgam (1 surface)	1	2	______
c. Place/finish amalgam (2+ surfaces)	1	2	______
d. Place/wedge matrix for composite	1	2	______
e. Place/finish anterior composite	1	2	______
f. Place/finish posterior composite (1 surface)	1	2	______
g. Place/finish posterior composite (2+ surface)	1	2	______
h. Place temporary filling material	1	2	______
Fixed Prosthodontics			
a. Place cord for a C&B impression	1	2	______
b. Take final C&B impression	1	2	______
c. Make temporary crown	1	2	______
d. Cement temporary crown	1	2	______
e. Remove temporary crown	1	2	______
f. Adjust permanent crown before cementation	1	2	______
g. Cement permanent crown	1	2	______
h. Initial placement/adjustment of stainless steel crown	1	2	______
i. Cement stainless steel crown	1	2	______
j. Make temporary bridge	1	2	______
k. Cement temporary bridge	1	2	______
l. Remove temporary bridge	1	2	______
m. Adjust permanent bridge before cementation	1	2	______
n. Cement permanent bridge	1	2	______
Removable Prosthodontics			
a. Take preliminary RPD impression	1	2	______
b. Take final RPD impression	1	2	______
c. Try RPD framework in mouth	1	2	______
d. Take preliminary CD impression	1	2	______
e. Take final CD impression	1	2	______
f. Take records for CD	1	2	______
g. Adjust RPD or CD	1	2	______
h. Rebase, reline, or repair denture	1	2	______
Periodontics			
a. Place subgingival medicaments	1	2	______
b. Scaling, root planing, and/or curettage	1	2	______

Question 23 cont.

	Not Performed	Not Delegated	% of Procedure
Endodontics			
a. Medicate root canal	1	2	______
b. Obturate root canal	1	2	______
Oral Surgery			
a. Place suture	1	2	______
b. Remove suture	1	2	______
Other			
a. Adjust orthodontic appliance	1	2	______
b. Place or remove orthodontic brackets/wires	1	2	______
c. Local anesthesia	1	2	______
d. Perform brush biopsy	1	2	______

24. In the table below, please indicate the number of procedures you performed **during a typical month in 2006** and the typical fee charged. If you have a practice management system such as Dentrix, Eaglesoft, etc., you may want use it to answer this question & question 25.

Procedure	Number of Procedures per MONTH	Typical Fee Charged ($)
Diagnostic/Preventive/Adjunctive		
Periodic oral evaluation (D0120)		$
Radiographs, complete series (D0210)		$
Prophylaxis – adult (D1110)		$
Topical application of fluoride (prophy not included) – child (D1205)		$
Sealant – per tooth (D1351)		$
Restorative		
Amalgam – two surfaces, primary or permanent (D2150)		$
Resin-based composite – one surface, posterior-permanent (D2385)		$
Single restoration: Crown – porcelain fused to high noble metal (D2750)		$
Fixed partial denture retainers: Crown – porcelain fused to high noble metal (D6750)		$
Removable Prosthodontics		
Complete denture – maxillary (D5110)		$
Mandibular partial denture – cast metal framework with resin denture bases (including any conventional clasps, rests and teeth) (D5214)		$
Periodontics		
Full mouth debridement to enable comprehensive evaluation and diagnosis (D4355)		$
Periodontal scaling and root planning – four or more teeth per quadrant (D4341)		$
Periodontal maintenance (D4910)		$
Endodontics/Oral Surgery		
Molar RCT (D3330)		$
Extraction, coronal remnants – deciduous tooth (D7111)		$
Removal of impacted tooth – completely bony (D7240)		$

In your best estimate, what percentage of all your procedures are represented in this list?

__________%

25. In **2006**, during a **typical month** in the **primary practice location**, what percentage of your time treating patients was spent in the following procedures and what percentage of your practice gross billings did they account for? (If none, enter zero.)

Procedure	% of your time	% of practice gross billings
a. Diagnostic (D0100 - D0999)	____ %	____ %
b. Preventive (D1000 - D1999)	____ %	____ %
c. Restorative (D2000 - D2999)	____ %	____ %
d. Endodontics (D3000 – D3999)	____ %	____ %
e. Periodontics (D4000 - D4999)	____ %	____ %
f. Removable prosthodontics (D5000 - D5899)	____ %	____ %
g. Fixed prosthodontics (D6200 - D6999)	____ %	____ %
h. Oral surgery (D7000 - D7999)	____ %	____ %
i. Orthodontics (D8000 - D8999)	____ %	____ %
j. Adjunctive general services (D9000 - D9999)	____ %	____ %
	total 100 %	total 100 %

26. Please provide the following information for each dentist position currently in the **primary practice location**. Please **include yourself**. If the dentist is a specialist, check the first box. If the dentist is an owner in this practice, check the second box. If the practice did not employ a dentist in each position, please leave the appropriate line(s) blank. (PLEASE PRINT.)

	If Specialist (check box)	If Owner (check box)	Annual Net Income/ Salary per Year	Weeks Worked per Year	Hours Worked per Week	Trained to use expanded duty auxiliaries?		Currently using expanded duty auxiliaries?	
			dollars	weeks	hours	Yes	No	Yes	No
DENTIST(S):									
Position #1	☐	☐	$ ____	____	____	1	2	1	2
Position #2	☐	☐	$ ____	____	____	1	2	1	2
Position #3	☐	☐	$ ____	____	____	1	2	1	2
Position #4	☐	☐	$ ____	____	____	1	2	1	2
Position #5	☐	☐	$ ____	____	____	1	2	1	2

27. Please provide the following information for each of the listed positions currently in the **primary practice location**. If the practice did not employ someone in each position, please check the appropriate box in the first column. (PLEASE PRINT.)

	Not Applicable (check box)	Annual Net Income/ Salary per Year	Weeks Worked per Year	Hours Worked per Week	Total Length of Experience in Dentistry	Trained to perform expanded duties? Formally		On the Job		Currently performing expanded duties?	
		dollars	weeks	hours	years	Yes	No	Yes	No	Yes	No
DENTAL HYGIENIST(S):											
Position #1	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #2	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #3	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #4	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #5	☐	$ ____	____	____	____	1	2	1	2	1	2
CHAIRSIDE ASSISTANT(S):											
Position #1	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #2	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #3	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #4	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #5	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #6	☐	$ ____	____	____	____	1	2	1	2	1	2
Position #7	☐	$ ____	____	____	____	1	2	1	2	1	2

Thank you for your assistance in this research project. Please return this questionnaire (and any printouts or disk/CD containing electronic production information) in the enclosed large white envelope. Drop it in the mail; postage is paid.

Appendix B

PRODUCTIVITY

By far the most commonly used and also the most easily understood measure of performance is *productivity.* In the simple case of a single output produced from a single input, it is merely the ratio of the output and input quantities. A producer with a higher output per unit of input used is more productive and is deemed to perform in a superior fashion. Consider this simple example involving five practices. Output is measured by the number of patient visits and is produced from a single input, dentist hours. The hypothetical input-output quantities are shown in Table A-1.

Table A-1: Productivity Measurement with One Input

	Practice A	Practice B	Practice C	Practice D	Practice E
Number of Visits	15	12	10	13	10
Dentist Hours	4	5	8	7	9
Visits per Dentist Hour	3.75	2.40	1.25	1.86	1.11

By this criterion, practice A, with the highest hourly productivity of a dentist performs best and practice E the worst. Note that number of visits per dentist hour is itself a descriptive measure summarizing the separate pieces of information about the output and the input quantity of a practice into a single ratio measure. In fact, dentist productivity becomes a measure useful for performance evaluation only in a comparative sense. For example, practice D with 1.86 visits per dentist hour is a relatively poor performer only when compared with practices like A and B.

It is seldom the case, however, that only a single input is used to produce the output. To make this example more realistic we include a second input, the number of chairside assistant hours used in conjunction with dentist hours to produce the number of visits shown in Table A-1. The chairside assistant hours were not reported in that table, but the more complete information on the input bundles and the output levels of the same five practices are now shown in Table A-2.

Table A-2: Productivity Measurement with Two Inputs

	Practice A	Practice B	Practice C	Practice D	Practice E
Number of Visits	15	12	10	13	10
Dentist Hours	4	5	8	7	9
Assistant Hours	9	2	8	6	8
Visits per Dentist Hour	3.75	2.40	1.25	1.86	1.11
Visits per Assistant Hour	1.67	6.00	1.25	2.17	1.25

This example clearly illustrates the problem associated with using partial productivity measures to evaluate performance. When productivity is measured as visits per assistant hour (rather than per dentist hour), practice B emerges as the best performer and practice A slips to the third position. The simple fact of the matter is that the output of a practice (in this case, visits) incorporates the contribution of both inputs (the dentist and the assistant). To use visit per dentist hour to evaluate performance amounts to ignoring the contribution of the assistant's time and shows the practices with more assistants per dentist in an unduly favorable light. What we need to do is to construct an *aggregate measure of the inputs* and to express productivity as the ratio of output to the aggregate input. But how is the aggregate input to be constructed? The task is simple when input prices are available and all practices face the same input prices. Suppose, for example, that the price of one dentist hour is $150 and the price of an assistant hour is $60. Then a measure of the composite input would be the total cost of the input bundle, and overall productivity (output per dollar spent on inputs) would be the inverse of the average cost (dollars spent on inputs per unit of output). Hence, in this special case, a firm with a lower average cost is a better performer.

Table A-3: Measuring Productivity through Average Cost

	Practice A	Practice B	Practice C	Practice D	Practice E
Number of Visits	15	12	10	13	10
Dentist Hours	4	5	8	7	9
Assistant Hours	9	2	8	6	8
Cost ($)	1140	870	1680	1410	1830
Cost per Visit ($)	76.00	72.50	168.00	108.46	183.00

In Table A-3, we can use average cost to rank the firms in reverse order of performance. Now firm B, with the lowest average cost, is the best performer followed closely by firm A. The practice with the lowest cost per visit is treated as the best performer and others are evaluated using this practice as the benchmark.

This approach is quite simple and appeals to common sense. But there are problems. First, when the different practices face different input prices, cost per visit is not a meaningful criterion because a lower average cost may reflect lower input prices rather than higher productivity. Second, and as is often the case, we may not have appropriate prices of all inputs. In that case, we need to get an aggregate or *total factor productivity* measure from the output and input quantities alone. Suppose that X_1 and X_2 measure the number of dentist hours and assistant hours used by a practice and y is the corresponding number of visits. A natural solution would be to take some average of the partial productivities for a measure of total factor productivity. For example, the average productivities of dentist and assistant hours of practice A are

$AP_1^A = \frac{y_A}{X_{1A}}$ and $AP_2^A = \frac{y_A}{X_{2A}}$.

Define its total factor productivity as the weighted geometric mean

$$TFP^A = \left(AP_1^A\right)^{\beta_1}\left(AP_2^A\right)^{\beta_2}$$

where $\beta_1 + \beta_2 = 1;\ \beta_1, \beta_2 > 0$. Here β_1 and β_2 are, respectively, the weights assigned to the dentist and assistant productivities. For example, if we set

$\beta_1 = 0.6$ and $\beta_2 = 0.4$, in this example

$$TFP^{A} = (3.75)^{0.6}\ (1.67)^{0.4} = 2.71.$$

For any individual practice *j* (*j = A, B, C, D, E)*

$$TFP^{j} = \left(\frac{y_j}{Xij}\right)^{\beta_1}\left(\frac{y_j}{X_{2j}}\right)^{\beta_2} = \frac{y_j}{X_j}; X_j = X_{1j}^{\beta_1} X_{2j}^{\beta_2}.$$

Note that here $X_j = X_{1j}^{\beta_1} X_{2j}^{\beta_2}$ becomes a measure of aggregate input. We may compare the total factor productivities of two firms B and A through the productivity index

$$TFPI_{B,A} = \frac{TFP_B}{TFP_A} = \frac{y_B/X_B}{y_A/X_A} = \frac{y_B/y_A}{X_B/X_A} = \frac{Q_y}{Q_x}.$$

This productivity index is known as the Tornqvist index and is the ratio of an output quantity index (Q_y) and an input quantity index (Q_X). If $TFPI_{B,A}$ exceeds unity, B is more productive than A. Otherwise, A is more productive.

The weights β_1 and β_2 are of critical importance in the definition of the aggregate input *X* and can have a significant impact on the how the total factor productivity is measured. When cost information is available, one can use the shares of the labor and capital input in the total cost for these weights. In the present example, the average share of dentist hours in total cost across the five practices shown in Table A-3 is 0.72. We use $\beta_1 = 0.72$ and $\beta_2 = 0.28$ to obtain the weighted geometric means of partial productivities to get the total factor productivities of the individual practices shown in Table A-4 below.

Table A-4: Measuring Total Factor Productivity

	Practice A	Practice B	Practice C	Practice D	Practice E
Number of Visits	15	12	10	13	10
Dentist Hours	4	5	8	7	9
Assistant Hours	9	2	8	6	8
Visit per Dentist Hour	3.75	2.40	1.25	1.86	1.11
Visit per Assistant Hour	1.67	6.00	1.25	2.17	1.25
Total Input	5.02	3.87	8.00	6.70	8.71
Total Factor Productivity	2.99	3.10	1.25	1.94	1.15

As previously noted, this procedure can be applied only when the shares of the individual inputs in the total cost are known. When that is not the case, one must either use judgment in selecting the weights or explore other avenues.

EFFICIENCY

While useful as a relative measure of performance, productivity (whether partial or total) has two major limitations. First, in general, the unit of measurement of the aggregate input is undefined. In the example considered, because both inputs are labor hours, the aggregate input may be interpreted as a weighted labor hour so that the total factor productivity is (in some sense) number of visits per hour. But no clear interpretation of the total input is possible when the individual inputs are measured in different units like hours (for dentist time) and physical units (like number of operatories). Second, a comparison of productivities of two different practices does not tell us anything about how many visits a particular practice should be able to produce from its actual numbers of dentist and assistant hours. For example, total factor productivity of practice B is 2.48 times the total factor productivity of practice C. This, does not mean, however, that from its observed inputs of 8 hours of dentist's time and 8 hours of assistant's time, practice C should be able to produce 24.8 (i.e., about 25) visits. That is because productivity is a descriptive measure and cannot be used to create a benchmark for production from a given bundle of inputs.

A more appropriate measure of the performance of a practice can be obtained by comparing its actual output (visits) with the maximum level of output producible from its observed bundle of inputs (i.e., the actual dentist and assistant hours). The maximum producible output (call it y^*) is by definition no smaller than the actual output y^0. The level of (technical) efficiency of a practice can be measured as

$$\tau = \frac{y^0}{y^*}.$$

Clearly τ lies between 0 and 1. Technical efficiency is 100% when the output actually produced (y^0) is equal to the maximum level of output that can be produced (y^*) from the inputs actually used by the practice. Obviously, technical efficiency is an index of resource utilization.

In order to operationalize this, however, we need to figure out the maximum quantity of output that can be produced from a particular input bundle. Conceptually, the *production function* defines the maximum output y^* that can be produced from a bundle of inputs (say x_1 and x_2) and is expressed as

$$y^* = f(x_1, x_2).$$

By implication, the measured level of technical efficiency is

$$\tau = \frac{y^0}{y^*} = \frac{y^0}{f(x_1^0, x_2^0)}$$

In the absence of any scientific formula exactly relating output to inputs, one must use an empirical method to construct the production function from observed input-output data.

Conventional Regression Analysis

The conventional approach in empirical estimation of a production function is to include a random disturbance term to permit deviations of the actual output produced from any input bundle from what is implied by the corresponding value of the production function. One starts with the conceptualization of the form

$y = f(x_1, x_2).e^v$ where v is a random disturbance term that can take positive as well as negative values.

COBB-DOUGLAS PRODUCTION FUNCTION

A widely used specification is the Cobb-Douglas production function

$$f(x_1, x_2) = A x_1^{\beta_1} x_2^{\beta_2}$$

This yields the regression model

$$\ln y = \alpha + \beta_1 \ln x_1 + \beta_2 \ln x_2 + v.$$

Here, $\alpha = \ln(A)$. One uses the observed values of the inputs (x_1, x_2) and output (y) from the sample practices in a linear regression model to obtain the estimated values $(\hat{\alpha}, \hat{\beta}_1, \hat{\beta}_2)$, which can then be used to get the values of y^* for the individual practices. Of course, when more than two inputs are used the regression model includes the appropriate number of explanatory variables.

A serious limitation of this approach is that linear regression methodology permits some of the observed data points to lie above the fitted line. But that implies that for some observations, the output level actually observed exceeds what is predicted as maximally producible from the corresponding input bundles. This clearly invalidates any interpretation of the fitted function as a *frontier*. The value predicted by the fitted model cannot be used as a benchmark for measuring technical efficiency. One simple and workable (although not the best) solution to this problem is to adjust the intercept by adding to it the largest positive regression residual. No observed data point will lie above this "corrected" frontier, and deviations from this revised frontier will all be either negative or zero. Hence, the output value predicted by this corrected frontier will be a valid benchmark for measurement of efficiency.

STOCHASTIC PRODUCTION FRONTIER ANALYSIS

A more refined approach to measuring efficiency using a frontier production function is to conceptualize the production function itself as shifting up or down due to favorable and unfavorable random shocks. In this specification

$y = y^* e^{-u}$ where $y^* = f(x_1, x_2).e^v$ and $u \geq 0.$

Here, although the maximum output producible from the input bundle (x_1, x_2) varies randomly, because e^{-u} is less than or equal to unity, when u is non-negative, the actual output never exceeds the (unobserved) frontier output. In the econometric specification, the Cobb-Douglas stochastic frontier production function takes the form

$$\ln y = \alpha + \beta_1 \ln x_1 + \beta_2 \ln x_2 + v - u.$$

Here *v* is assumed to have the usual Normal distribution, while *u* is specified to have some one-sided distribution like the Normal distribution truncated from below at 0. One uses maximum likelihood procedures to estimate both the model parameters and the measure of technical efficiency (e^{-u}) for each observation in the sample.

Relation between Productivity and Efficiency

We now return to the measure of total factor productivity discussed before and take a closer look at the input aggregator function

$$X = f(x_1, x_2) = x_1^{\beta_1} x_2^{\beta_2}; \beta_1 + \beta_2 = 1; \ \beta_1, \beta_2 > 0.$$

A production function exhibits constant returns to scale when any equi-proportionate change (increase or decrease) in all inputs also results in exactly the same proportionate change in the output. It is easy to see that $f(x_1,x_2)$ in X can be regarded as a Cobb-Douglas production function exhibiting constant returns to scale. This, however, is a consequence of our decision to take a weighted geometric mean of the partial productivities as a measure of total factor productivity. In fact, we could use *any* production function exhibiting constant returns to scale and non-negative marginal productivities to define the aggregate input and derive the productivity index.

It is important to note that if the production function does not exhibit constant returns to scale, higher productivity would not necessarily imply higher efficiency. Suppose, for simplicity, that only one input, x_1, is needed to produce the output *y*. Suppose that practice #1 uses 4 units of the input to produce 15 units of the output while practice #2 produces 24 units of the output from 9 units of the input. In that case, the average productivity of practice #1 is 3.75, while #2 has a lower average productivity of 2.67. Now suppose that the production function is

$$y^* = f(x_1) = 10\sqrt{x_1}.$$

In that case, the maximum producible output from the input used by practice #1 is 20 and its technical efficiency is $\tau_1 = \frac{15}{20} = 0.75$. On the other hand, the maximum output producible from 9 units of the input is 30 and the technical efficiency of practice #2 is $\tau_2 = \frac{24}{30} = 0.80$. Practice #2 has a lower productivity but higher efficiency than practice #1. This anomaly arises out of the fact that the production function exhibits diminishing returns to scale. Average productivity declines as the input level increases, *even when there is no inefficiency.* Unless constant returns to scale holds, technical efficiency is a better measure than productivity for performance evaluation.

DATA ENVELOPMENT ANALYSIS AND MEASUREMENT OF TECHNICAL EFFICIENCY

Validity of any estimated stochastic production frontier as the benchmark for evaluating the efficiency of an observed input-output bundle crucially depends on the appropriateness of the functional form of the estimated model. Choice of the preferred functional specification is often arbitrary and is driven by computational simplicity and tractability. Additionally, the stochastic distribution of the one-sided inefficiency term (e.g., half-Normal vs. exponential) is a matter of preference for the analyst. The nonparametric method of Data Envelopment Analysis (DEA) requires no parametric specification of the production frontier and relies on a number of fairly general assumptions about the nature of the underlying production technology. DEA uses a sample of actually observed input-output data and a set of assumptions to derive a benchmark output quantity with which the actual output of a firm can be compared for efficiency measurement.

Because the DEA methodology is entirely data driven, it is best explained with a numerical example. Suppose that we observe six different producers (practices) using a single input, *x* (dentist time), to produce a single output *y* (visits). The input-output quantities for this example are as shown in the Table A-5.

Table A-5: Hypothetical Input/Output Data for DEA

	Practice 1	Practice 2	Practice 3	Practice 4	Practice 5	Practice 6
Output (y)	8	18	24	25	11	20
Input (x)	4	6	8	10	7	9

Our objective is to evaluate the technical efficiency of practice #5. For this we need to figure out: *What is the maximum quantity of y that can be produced from 7 units of x?*

To answer a question like this we have to make four simple assumptions about the technology:

1. All actually observed input-output pairs are feasible. That is, if we find any producer (or practice) producing output y^0 using input x^0, then any other practice could do the same.

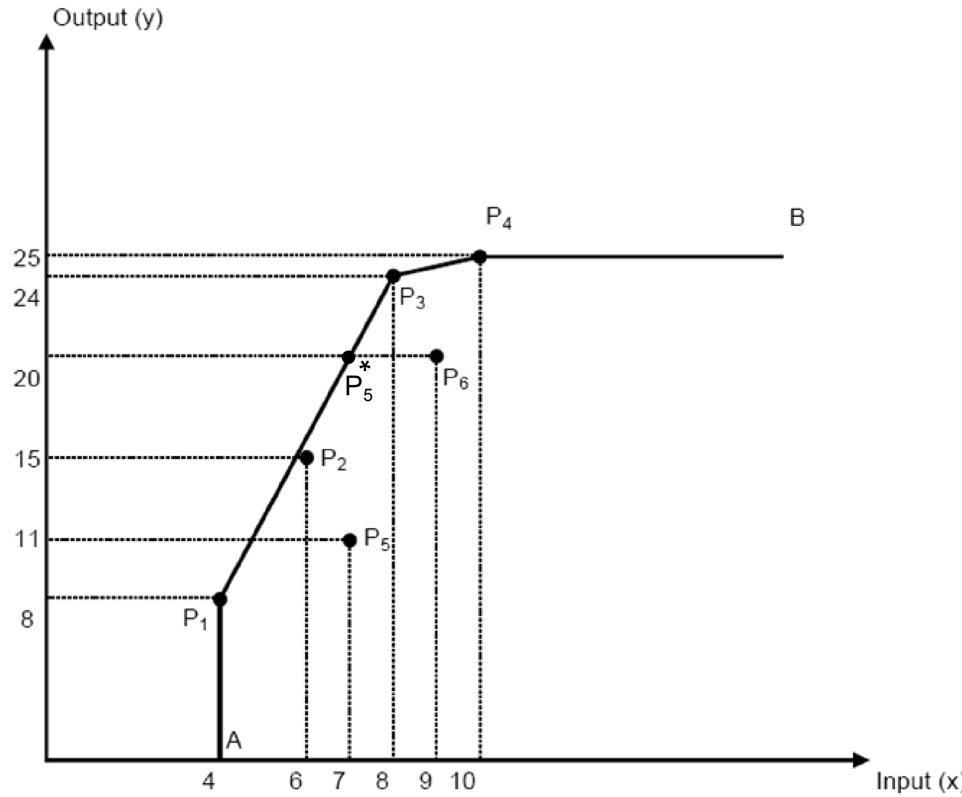
2. Increasing the input quantity would not lower the output.

3. A lower level of output can always be produced from a given input bundle by leaving some of the input less than fully utilized.

4. If two input-output bundles are feasible, then any weighted average of the input quantities can produce at least the corresponding weighted average of the corresponding output quantities.

We can construct the frontier using the data in Table A-5 and assumptions 1 through 4 as shown in Figure A-1.

Figure A-1



In this diagram, points P_1 through P_6 show the observed input-output quantities of the individual practices reported in Table A-5. The empirically constructed frontier is shown by the broken line $AP_1P_3P_4B$. The set of feasible input-output combinations are the points on or below the frontier. The point P_1 is an actually observed input-output combination and is therefore feasible. The vertical segment AP_1 consists of points where the input remains the same as in P_1 but the output is lower. Hence, all such points are feasible by assumption 3. All points on the P_1P_3 segment of the frontier are weighted averages of the points P_1 and P_3. Hence, by assumption 4, they are feasible. Similar reasoning holds for points on the P_3P_4 segment. Next, every point on the horizontal segment P_4B represents greater quantities of the input but no more output than what is observed at point P_4. Hence, by assumption 2, they are all feasible points. Finally, any point below the frontier represents either less output but no less input or more input but no more output when compared with some point on the frontier.

As argued above, all points on the frontier are feasible input-output bundles; interior points are also feasible by assumptions 2 and 3. This frontier, constructed using only the observed data and assumptions 1 through 4, is called a nonparametric frontier because we do not specify an explicit form (e.g., Cobb-Douglas) of the production frontier.

We now return to the question of measuring the technical efficiency of practice #5. The benchmark for comparison would be the point P_5^* on the frontier where the input quantity used 7 (as in the case of practice #5) but the output produced is 20. It can be seen that the input-output bundle at P_5^* (*x=7, y=20*) is the weighted average of the input and output quantities of practice #1 (*x=4, y=8*) and practice #3 (*x=8, y=24*). The weights attached are 0.25 to practice #1 and 0.75 to practice #3. A nonparametric measure of the technical efficiency of practice #5 is

$$\tau_5 = \frac{y_5}{y_5^*} = \frac{11}{20} = 0.55.$$

This implies that the actual output of practice #5 is only 55% of the maximum output that could be produced from the input quantity that it is using.

DEA WITH MULTIPLE INPUTS

The 1-input/1-output example considered above is simple enough to be shown graphically. But what happens when the number of inputs and outputs exceeds three? A simple graphical analysis will not be possible anymore. But we can set it up as an algebraic problem to be solved by an optimization method known as linear programming. For an example we return to the data shown earlier in Table A-2. Suppose that we wish to evaluate the efficiency of practice C which produces 10 visits using 8 hours of dentist time and 8 hours of assistant time. Visual inspection shows that if we created a (*2/3, 1/3*) weighted average of the input-output bundles of practices A and D, the benchmark input bundle would include $(\frac{2}{3}.4 + \frac{1}{3}.7) = 5$ dentist hours, $(\frac{2}{3}.9 + \frac{1}{3}.6) = 8$ assistant hours, and would produce $(\frac{2}{3}.15 + \frac{1}{3}.10) = \frac{43}{3} = 14\frac{1}{3}$ visits. Note that the benchmark input bundle would use strictly fewer dentist hours and just as many assistant hours as practice C and would still produce $14\frac{1}{3}$ visits compared to 10 visits actually produced by C. Hence, C should be able to produce at least as many visits from its observed input bundle. Thus, a measure of the technical efficiency of C would be no more than $\frac{30}{43} = 0.697$.

The question is: *Is this the maximum output producible from the input bundle of C?* Is there some other weighted average of actual input-output bundles that could produce an even higher output quantity without increasing any input compared to C? To answer this question, we solve the following linear programming (LP) problem:

Max φ

Subject to

$$15\lambda_A + 12\lambda_B + 10\lambda_C + 13\lambda_D + 10\lambda_E \geq 10\varphi;$$
$$4\lambda_A + 5\lambda_B + 8\lambda_C + 7\lambda_D + 9\lambda_E \leq 8;$$

$$9\lambda_A + 2\lambda_B + 8\lambda_C + 6\lambda_D + 8\lambda_E \leq 8;$$

$$\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E = 1;$$

$\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E \geq 0; \varphi$ unrestricted.

Here, the λs are the weights assigned to the input-output bundles of the individual practices. They are restricted to be non-negative and are constrained to add up to 1 (or 100%). The left-hand sides of the three inequalities are the output and input quantities of the benchmark bundle that is created by taking a weighted average. Our objective is to seek the weights that lead to the highest value of the left-hand side of the first inequality (call it y_C^*) without violating the other two inequality constraints. Note that y_C (the actual output of C) is 10. Hence, the implied technical efficiency of C would be

$$\tau_C = \frac{y_C}{y_C^*} = \frac{1}{\varphi}.$$

In the present example, the optimal weights are:

$$(\lambda_A = 0.857, \lambda_B = 0.143, \lambda_C = \lambda_D = \lambda_E = 0).$$

The maximum value of φ is 1.4571. Thus, the technical efficiency of C is

$$\tau_C = \frac{y_C}{y_C^*} = \frac{1}{\varphi}. = 0.686.$$

Thus, a (0.857;0.143) weighted average of the bundles of A and B will produce 14.571 units of the output while using just as many assistant hours as C and no more dentist hours than C uses. In fact, it would actually use only 4.143 (i.e., 3.857 fewer) dentist hours compared to the 8 hours used by C and would still produce this higher output level.

A Multiple Output Multiple Input Case

One of the main advantages of DEA is that unlike the frontier production function analysis, it can easily handle multiple output technologies. It is useful to illustrate this with an example. For this, we modify the input-output data shown in Table A-2 by considering two different kinds of visits: endodontic (EN) and diagnostic/restorative (DR). The revised data are presented in Table A-6.

Table A-6: Data for Two-Output Two-Input DEA Application

	Practice A	Practice B	Practice C	Practice D	Practice E
Visits:					
Endodontic	6	4	3	5	6
Restorative/Diagnostic	9	8	7	8	4
Hours:					
Dentist Hours	4	5	8	7	9
Assistant Hours	9	2	8	6	8

As in the preceding example, we measure the technical efficiency of practice C. This time, we search for the *maximum rate at which both outputs can be increased at the same time* without requiring any additional input of either dentist or assistant hours. The relevant DEA problem for this multiple-output multiple-input case is:

Max φ

Subject to

$$6\lambda_A + 4\lambda_B + 3\lambda_C + 5\lambda_D + 6\lambda_E \geq 3\varphi;$$

$$9\lambda_A + 8\lambda_B + 7\lambda_C + 8\lambda_D + 4\lambda_E \geq 7\varphi;$$

$$4\lambda_A + 5\lambda_B + 8\lambda_C + 7\lambda_D + 9\lambda_E \leq 8;$$

$$9\lambda_A + 2\lambda_B + 8\lambda_C + 6\lambda_D + 8\lambda_E \leq 8;$$

$$\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E = 1;$$

$\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E \geq 0; \varphi$ unrestricted.

This time, there are two separate constraints for the two distinct outputs. As before, we select the λs as weights to create a benchmark input-output bundle for comparison with the actual bundle of practice C. The left-hand sides of the first four constraints are the two output quantities and the two input quantities in this benchmark bundle, call them $(y^*_{1C}, y^*_{2C}; x^*_{1C}, x^*_{2C})$. We require that x^*_{1C} and x^*_{2C} should be no greater than the actual inputs of C (x_1^C, x_2^C). Further, we seek the largest value of φ that is less than both $\frac{y^*_{1C}}{y_1^C}$ and $\frac{y^*_{2C}}{y^C_{2C}}$. That is, $\varphi = \min\left\{\frac{y^*_{1C}}{y_1^C}, \frac{y^*_{2C}}{y_2^C}\right\}$. The optimal weights for this problem are $(\lambda_A = 0.857, \lambda_B = 0.143, \lambda_C = \lambda_D = \lambda_E = 0)$ as in the single output (total visits) problem. That, however, is a coincidence and usually the two sets of weights would be different. But, even though the optimal weights are the same as before, the optimal value of φ is 1.2653. The benchmark bundle would have

5.714 units of output 1 (endodontic visits) and 8.857 units of output 2 (diagnostic/restorative visits). Both outputs can be increased by 26.53% while output 2 can be increased by another 1.9183 units. In this example, the technical efficiency of C is

$$\tau_C = \frac{1}{1.2653} = 0.7903.$$

Input-Oriented Measures of Technical Efficiency

In the foregoing analysis, the primary focus has been on the maximum quantity of output producible from a given input bundle. An implicit assumption behind this is that there is no demand constraint. In reality, however, a practice might be producing less than the maximum output (visits) simply because there is not enough demand. In that case, an output-oriented measure of efficiency would be an inappropriate index of its performance. When output is exogenously given, either by market demand or as an assigned task, efficient utilization of resources lies in producing the target output with as little input use as possible.

For a simple example of input-oriented technical efficiency, consider again the data shown in Table A-6 above. This time, we want to evaluate practice D. It is clear that the observed output bundle of practice D $(y_{1D} = 5, y_{2D} = 8)$ can be produced with less of both inputs than practice D is using. Take the simple average of the input-output bundles of practice A and practice B. This average bundle would produce, from 4.5 units of x_1 (dentist's time) and 5.5 units of x_2 (assistant's time), 5 units of y_1 (endodontic visits) and 8.5 units of y_2 (preventive/restorative visits). Because this output bundle meets or exceeds both of D's observed outputs, it would be a feasible input bundle for producing D's outputs. As can be seen, compared to D's actual inputs, x_1 could be scaled down by a factor of 0.643 and x_2 could be scaled down by a factor of 0.917. Hence, while both inputs could be reduced by at least 8.3%, the dentist input could be reduced even further. Thus, D's input-oriented efficiency is no more than 91.7%. But this is not the best we can do. To find the maximum reduction in the inputs possible, we solve the following input-oriented DEA linear programming model:

Min θ

Subject to

$$6\lambda_A + 4\lambda_B + 3\lambda_C + 5\lambda_D + 6\lambda_E \geq 5;$$

$$9\lambda_A + 8\lambda_B + 7\lambda_C + 8\lambda_D + 4\lambda_E \geq 8;$$

$$4\lambda_A + 5\lambda_B + 8\lambda_C + 7\lambda_D + 9\lambda_E \leq \theta 7;$$

$$9\lambda_A + 2\lambda_B + 8\lambda_C + 6\lambda_D + 8\lambda_E \leq \theta 6;$$

$$\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E = 1;$$

$\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E \geq 0; \theta$ unrestricted.

The optimal solution for this problem is

$$(\lambda_A = 0.4, \lambda_B = 0.5, \lambda_C = \lambda_D = 0, \lambda_E = 0.1; \theta = 0.9).$$

The benchmark input-output bundle $(x_{1D}^* = 5, x_{2D}^* = 5.4; y_{1D}^* = 5; y_{2D}^* = 8)$ is a 40%, 50% and 10% weighted average of the bundles of A, B, and E, respectively. Both of D's output targets are met. Both inputs can be reduced by at least 10%. The dentist input can be reduced further by another 1.3 units. The technical efficiency measure is

$$\theta^* = \max\left\{\tfrac{5}{7}; \tfrac{5.4}{9}\right\} = 0.90.$$

It should be noted that compared to a benchmark constructed as the simple average of the input-output bundles of A and B, this weighted average of A, B, and E is superior *only in the sense that it allows a greater reduction in all inputs simultaneously.* When there is no prior information about the market valuation of the individual inputs, reducing each input would have equal priority. When we do have price information, reducing the more expensive input would get a higher priority. The objective then would be to find the least expensive bundle that could produce the target output bundle. One might even want to *increase* some input that would allow a reduction in the other inputs in a way that *reduces the total cost.* In the present example, when the cost of a dentist's time is $150 per hour and the assistant's time is $60 per hour, the simple average of the bundles of A and B costs $1050 and represents the cost efficient bundle. Although the weighted average bundle is the most technically efficient for D, when input prices are considered, it is not the most cost efficient one.

DETERMINANTS OF TECHNICAL EFFICIENCY: THE ROLE OF OTHER FACTORS

The actual output produced by a firm from a given bundle of inputs depends on a number of factors that affect its ability to efficiently utilize the inputs. Some of these factors are favorable and enhance efficiency. Others may be detrimental and hinder efficient utilization of resources. In the context of dental care, a practice serving a well educated, upper middle class, suburban clientele would have fewer missed appointments compared to a practice located in an urban district where a majority of the clients are low income, often without personal means of transportation, and with little or no insurance coverage. These are factors that affect how many visits or how much gross billings could be generated from the same bundle of resources. While it is agreed that such factors should be taken into account explicitly, there are two different ways to model the production process to include these attributes.

One approach would specify the production frontier as $y^* = f(x,a)$, where *x* is the input bundle and *a* is the set of attributes affecting output. The actual output is then related to the frontier as

$$y = f(x,a) \cdot \tau;\ 0 \le \tau \le 1.$$

Here, τ is the measure of technical efficiency of the firm. In this conceptualization, the set of attributes shifts the production function outwards (if favorable) and inwards (if detrimental). The level of technical efficiency of a firm (i.e., a practice) would be measured relative to a frontier appropriately positioned in light of its observed attributes.

In the alternative approach, these attributes are treated as facilitating or hindering resource utilization relative to a given frontier production function that does not depend on the attributes. In this approach, actual output relates to the frontier as

$$y = f(x) \cdot \tau(a);\ 0 \le \tau(a) \le 1.$$

Here, the frontier production function $y^* = f(x)$ does not depend on *a*. The attributes only affect the technical efficiency, τ.

In DEA, the first approach would involve specifying a linear programming problem that incorporates constraints for the individual attributes along with the constraints for the input quantities. By implication, the frontier itself depends on the attributes. The other approach, which is the more popular one, leaves the attributes out of the DEA specification and, once the efficiency scores are obtained, a second stage k-variable regression model

$$\tau = \beta_0 + \beta_1 a_1 + \beta_2 a_2 + \ldots + \beta_k a_k + u$$

is estimated to determine how any individual attribute, a_j, affects the DEA efficiency scores.

An advantage of the 2-stage approach is that one need not specify beforehand whether any individual attribute enhances or hinders efficiency.

RETURNS TO SCALE

None of the four assumptions that we made about the technology had anything to do with returns to scale. "Returns to scale" is a property of the frontier of the production possibility set. When a small equi-proportionate increase in all inputs causes a more than proportionate increase in all outputs along the frontier, locally increasing returns to scale prevail. Similarly, locally diminishing returns to scale occur when the proportionate increase in outputs is lower than the proportionate increase in inputs. In the case of constant returns to scale, outputs and inputs increase (or decrease) by the same proportion along the frontier. It is possible that the technology exhibits increasing, constant, or decreasing returns to scale along different segments of the frontier. This *Variable Returns to Scale (VRS)* is the more general assumption about the production technology. If, however, one assumes that *Constant Returns to Scale (CRS)* holds everywhere along the frontier, definition of the production possibility set and the resulting measure of technical efficiency will change. An implication of the (global) CRS assumption is that if any input-output bundle *(x, y)* is feasible, then the bundle *(tx, ty)* is also feasible for any non-negative *t*. As explained by Ray (2004), under the assumption of CRS, the corresponding construction of the production possibility set would be

$$S^C = \left\{ (x, y) : x \geq \sum_{j=1}^{N} \lambda_j x^j ; y \leq \sum_{j=1}^{N} \lambda_j y^j ; \lambda_j \geq 0 \, (j = 1,2,..., N) \right\}.$$

Here, the superscript *C* indicates that CRS has been assumed. Note the absence of the constraint for λs to sum to 1. This equality constraint will also be removed from the output- or input-oriented DEA linear programming problems when CRS is assumed. Note that the removal of the constraint makes the CRS DEA problems less restrictive than the corresponding VRS models. As a result, φ^* will either be higher or stay the same when compared with the optimal solution of the VRS problem. Similarly, θ^* from the CRS problem will be either strictly lower or equal to what is obtained under VRS. This means that measured technical efficiency under CRS will be less than or equal to what is obtained under the VRS assumption. Moreover, when CRS is assumed, the input- and output-oriented measures will be identical. This is not the case under the VRS assumption. Note that the technical efficiency is strictly lower under the CRS assumption. Further, the λ-weights do not sum to 1 in this case.

Appendix C

According to the information provided to the research team, your dental practice is a solo incorporated general dental practice with four fully equipped operatories and seven dental auxiliaries.

EFFICIENCY SCORE OF YOUR PRACTICE

Using the following characteristics of your practice as well as those of a sample of 116 Colorado general dental practices:

- 2005 gross billings;
- Dentist hours;
- Dental hygienist hours;
- Chairside staff hours;
- Other staff hours;
- Square feet of office space;
- Number of operatories;
- Laboratory expenses;
- Expenses for supplies;

and Data Envelopment Analysis (DEA), a sophisticated mathematical programming model, five actual dental practices from this sample of 116 other practices have been identified by the model as your benchmark practices. The weighted average of these benchmark practices constitutes the **benchmark practice** relative to which your practice is assessed. Specifically, the DEA evaluates the "efficiency" of your practice by comparing its actual dental input and output (dental services) quantities with the selected benchmark practice inputs and output.

Based on this evaluation, your efficiency score in gross billings was estimated to be 0.861—or 86.1%. Your efficiency score is the ratio of the annual gross billings you indicated on the survey to that of the benchmark practice.

Figure 1 below displays the range of efficiency scores across 117 Colorado practices.

Figure 1

In addition to the *efficiency score* estimate of your practice, DEA allows for estimates of the required quantities of each input for the benchmark practice to produce the *maximum* ($882,700) and the *reported* ($760,000) level of gross billings. The "**used**" column in Table 1 displays the reported input levels used by your practice, the "**needed**" column indicates the input levels needed by the benchmark practice to produce the annual gross billings you reported on the survey, and the "**potential**" column indicates the input levels required to produce the higher gross billings of the benchmark practice.

Table 1

Your efficiency score = 0.861 or 86.1%
Your practice gross billings = $760,000
Maximum gross billings of benchmark practice = $882,700

Inputs	Used	Needed	Potential
Dentist hours	1344	1210	1344
Dental hygienist hours	2400	1914	1954
Chairside assistant hours	2545	2290	2545
All other staff hours	2370	2133	2127
Square feet of office space	2000	1583	1825
Number of operatories	4	3	4
Laboratory expenses	69157	61976	69157
Dental supply expenses	48819	43936	48819

It should be noted that the efficiency score and the comparison between inputs *used*, *needed* and *potential* reflects your personal preferences and practice philosophy as well as the market conditions in which your practice operates (e.g., location, fees, and patients' characteristics).

CONTRIBUTION OF EACH INPUT

Production function analysis is often used to describe the technical relation between the output of a firm and the production inputs used to produce it—i.e., it estimates how output will vary when different amounts of various inputs are utilized. Using this type of analysis and all data from the practices that responded to the survey, we estimated the contribution of key inputs to the output—measured by 2005 gross billings—of a dental practice. **These estimates reflect mean values rather than specific values for your practice**. The key inputs used in the estimation are listed in Table 2 along with the percent change in gross billings associated with a 10% change in each input. For example, a 10% increase in dentist hours would increase output by 3.99%.

Table 2

10% increase in input:	Percent increase in gross billings
Dentist hours	3.99%
Non-dentist staff hours	5.74%
Office space	1.71%

LEVEL OF DELEGATION

Two questions on the survey instrument dealt with delegation. In one question (Q20), dentists were asked if they currently use, or at one time used, expanded function auxiliaries in their primary practice locations. The results across all respondents are shown in Table 3. Clearly, over 62% of the sampled practices delegate some activities to their auxiliary.

Table 3

Q20: Do you currently use, or at one time used, expanded function auxiliaries in your primary practice location?

	N	Percent
Yes, currently use	102	62.2%
Yes, once used but have discontinued	21	12.8%
No, never used	41	25.0%

In another question (Q23), dentists were also asked to indicate the level of delegation across many specific activities. Tables 4A-4H show the results across all these activities.

Table 4A: Diagnostic/Preventive/Adjunctive

Take PA or BW radiographs	(95.85%, N=163)
Take panoramic radiographs	(97.01%, N=116)
Provide prophylaxis	(91.88%, N=152)
Place occlusal sealant(s)	(64.16%, N=122)
Administer topical fluoride	(96.69%, N=156)
Apply fluoride varnish	(90.01%, N=106)
Take and pour alginate impressions	(86.56%, N=160)

Table 4B: Operative, Primary and Permanent Teeth

Place wedge/matrix for amalgam	(34.59%, N=78)
Place/finish amalgam (1 surface)	(40.08%, N=66)
Place/finish amalgam (2+ surfaces)	(38.25%, N=64)
Place/wedge matrix for composite	(36.79%, N=89)
Place/finish anterior composite	(39.11%, N=74)
Place/finish posterior composite (1 surface)	(39.44%, N=82)
Place/finish posterior composite (2+ surface)	(35.04%, N=79)
Place temporary filling material	(46.39%, N=119)

Table 4C: Fixed Prosthodontics

Place cord for a C&B impression	(52.58%, N=99)
Take final C&B impression	(38.03%, N=77)
Make temporary crown	(71.48%, N=130)
Cement temporary crown	(69.88%, N=136)
Remove temporary crown	(68.29%, N=129)
Adjust permanent crown before cementation	(48.68%, N=79)
Cement permanent crown	(32.80%, N=65)
Initial placement/adj of stainless steel crown	(24.63%, N=43)
Cement stainless steel crown	(36.07%, N=46)
Make temporary bridge	(67.27%, N=102)
Cement temporary bridge	(69.98%, N=108)
Remove temporary bridge	(65.78%, N=113)
Adjust permanent bridge before cementation	(44.21%, N=72)
Cement permanent bridge	(29.97%, N=63)

Table 4D: Removable Prosthodontics

Take preliminary RPD impression	(80.71%, N=130)
Take final RPD impression	(49.01%, N=75)
Try RPD framework in mouth	(31.40%, N=63)
Take preliminary CD impression	(75.31%, N=109)
Take final CD impression	(37.20%, N=65)
Take records for CD	(28.82%, N=61)
Adjust RPD or CD	(37.67%, N=85)
Rebase, reline, or repair denture	(37.82%, N=72)

Table 4E: Periodontics

Place subgingival medicaments	(75.93%, N=108)
Scaling, root planing, and/or curettage	(89.50%, N=136)

Table 4F: Endodontics

Medicate root canal	(10.16%, N=45)
Obturate root canal	(1.19%, N=42)

Table 4G: Oral Surgery

Place suture	(0.22%, N=46)
Remove suture	(46.15%, N=103)

Table 4H: Other

Adjust orthodontic appliance	(26.55%, N=29)
Place or remove orthodontic brackets/wires	(44.13%, N=23)
Local anesthesia	(18.41%, N=97)
Perform brush biopsy	(23.75%, N=40)

Based on the reported percent delegation of the procedures listed in Tables 4A-4H, two overall indices of delegation were created:

- The first is the simple average across all activities with a mean value of 31.43%.
- The second is a weighted average (the weights being the shares in gross billings of category of services) across all activities with a mean value of 23.39%.

CONTRIBUTION OF DELEGATION

Using information from both Q20 and Q23, we have assessed the impact of delegation on **gross billings**, **value added** (gross billings minus expenses for supplies and commercial labs), **visits**, and **efficiency**. The results indicate that delegation matters on all these dimensions (i.e., gross billings, value added, visits and efficiency). Table 5 displays the impact of delegation on gross billings using three measures of delegation. **These estimates reflect mean values rather than specific values for your practice**.

The first measure uses information from Q20 (see Table 3 for question text). As shown in Table 5, the gross billings of those who said they currently used expanded function auxiliaries when responding to Q20, were on average 10.7% higher compared to those who picked either of the other two responses of "*Yes, once used but have discontinued*," and "*No, never used*."

The estimated impact of delegation on gross billings using either the simple average or the weighted average depends on the level of delegation. Table 5 provides estimates of this impact at mean values of delegation. For practices with higher (lower) values of delegation, the estimated impact would be higher (lower) than indicated in Table 5.

Table 5

Delegation measure	Percent change in gross billings
Delegation yes=1, no=0*	10.7%
Index simple, at mean value	17.0%
Index weighted, at mean value	4.8%

* In the analysis assessing the impact of delegation, the categories of "Yes, once used but have discontinued," and "No, never used" in Q20 were combined to indicate no delegation.

YOUR LEVEL OF DELEGATION

When asked: "*Do you currently use, or at one time used, expanded function auxiliaries in your primary practice location?*" You answered: "*Yes, currently use.*" Using the percentages you indicated for the level of delegation across the specific activities listed in Q23 and Tables 4A-4H:

Your simple average delegation index was: 12.76
Your weighted average delegation index was: 1.31

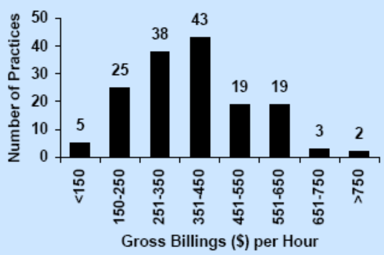
OUTPUT PER DENTIST HOUR

Below are three key indicators for your practice based on selected information you provided.

Practice gross billings per hour:	$565.48
Value added per hour:	$477.70
Visits per hour:	1.43

Figure 2 displays the range of practice gross billings across all practices who responded.

Figure 2



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