An Economic Framework for Teleconsultation

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ABSTRACT

Using microeconomic principles we analyze the determinants that maximize the applicability and efficacy of teleconsultations. The purpose of the analysis is threefold. First we outline a model that identifies disease characteristics for which teleconsultations can be expected to generate health benefits that exceed those derived from local care. Secondly, we clarify the conditions under which teleconsultations are less expensive than a referral. Perhaps most importantly, we provide guidelines that determine how to design teleconsultation systems to minimize costs to the health care system while maximizing their applicability.
We model healthcare organizations as health care providers or clinics that generate different levels of "health benefits." The provision of the exact health benefit is then modeled as a process in which provider inputs (e.g. equipment and skills) may exhibit some degree of substitutability. The provider's cost structure then highlights that alternate input combinations are associated with both, different costs and differential health benefits. Our results inform both policy and health organization decision makers in their efforts to determine the most effective deployment of health practitioners and technologies.

Keywords: *Teleconsultation; TeleMedicine; Economic Application; Model*

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I. INTRODUCTION

Teleconsultations - the use of communications infrastructure to deliver healthcare services - has been heralded as an important opportunity to improve quality and reduce the cost of healthcare. Applications of rapidly emerging technologies will profoundly affect both patients and providers. Since a ubiquitous, low cost communications infrastructure is quickly becoming reality, questions involving teleconsultation should now shift from investigations of technical feasibility to an exploration of efficient implementation.

Decision makers, faced with the prospect of ever tightening budgetary constraints, are requiring guidance whether and under what conditions allocations of scarce financial resources to teleconsultation technologies may generate improvements in both, care and costs. This paper provides a comprehensive analytic framework that can be used by health organization managers and policy makers as they seek an allocation of resources that is both economically efficient and health benefit maximizing.

Microeconomics is the study of the decisions and actions of both consumers and producers who face limited resources. Existing microeconomic principles provide a convenient framework to be applied to the analysis of teleconsultation by viewing the health care system as consisting of individuals (patients) and producers (health care providers) who make decisions that maximize the quality of care and minimize costs. Since both patients and providers face resource constraints, the costs associated with the consumption / provision of health care are the common element that drives decisions about what quality health care to provide and/or purchase.

We leverage the microeconomic framework to model a health care system as providers who transform inputs (equipment quality and skill level of health practitioners) into outputs (e.g. a service we call the "health benefit"). We follow the microeconomic literature and assume that health care organizations can incrementally adjust the health benefit they provide by controlling input levels. They do so by choosing which quantities of medical equipment and skills to place in a specific clinic. Since these choices are associated with the costs that consumers are expected to bear, market forces will, over time, select those practices that provide the greatest benefit at the lowest cost. The key insight is that health care organizations that consistently produce a health benefit at relatively lower cost than their competitors dominate a competitive marketplace

We model the process of efficient health care delivery by assuming that the management team of a health care entity (e.g., an HMO), is charged with the task of producing health benefits while facing resource constraints that require savvy control over the type and quantity of resources deployed to clinic(s) they control. Specifically, the management team must make choices concerning the clinic's equipment (its volume and sophistication) as well as the targeted level of skill for the practitioners. From an economic perspective, the question then reduces to an identification of the optimal combination of Skills (S) and Equipment (E) that produce the maximum health benefit at minimal cost.

II. SUBSTITUTABILITY OF INPUTS

To begin our analysis, we follow the economic literature and assume these inputs are to some degree substitutable. An example of equipment substituting for a practitioner's skill can be provided by those who argue that computer programs grounded in evidence based medicine may replicate (e.g. be substituted for) to some extent some capacities of a specialist. The extent to which substitution is feasible (for any specific health condition) can be represented by constructing a contour line in the E*S plane that represents all combinations of Equipment (E) and Skill (S) which generate a specific health benefit. Such contour lines can be labeled "iso-benefit lines" since they denote all combinations of skill and equipment that generate equal (greek: iso) health benefits. Iso-benefit lines that indicate greater health benefit are located to the northeast of the quadrant.

The shape of the iso-benefit lines indicates the degree to which skills and equipment are substitutable. Perfect substitutability, where equipment and skill are completely interchangeable, implies linear diagonal iso-benefit lines. The other extreme occurs when equipment and skill are used in fixed proportions and can never be substituted for one another. In this case the iso-benefit lines are right angles with sides parallel to the axes. Most production processes (including those involving health care) can be assumed to lie between these extremes.

In formulating the provision of health benefits, we specify that skills and equipment are to some degree interchangeable and model the generation of health benefits (B) as a function of Distance to medical Knowledge or Skills (S) and distance to medical equipment (E):

$$B = AE^{\alpha} S^{\beta}$$

where *A*, α, and β are disease specific parameters that can be empirically determined. Conditions that are easily managed and where minimal application of skills and equipment produce a large health benefit possess a large "*A*". Those diseases that rely heavily on the skills of a practitioner (e.g. neurosurgical procedures) exhibit a large β, and health benefits that rely crucially on equipment (such as brain tumor diagnoses) feature a large α. Our equation that formalizes the health benefit provision also highlights that any specific health benefit can be produced by many combination of skills and equipment. However, to generate a higher level of health benefits the increased usage of at least one factor (skills or equipment) is required.

To focus the discussion on teleconsultation, we note that a practice or clinic has specific values for E and S at any point in time. This allows us to assign each practice or clinic a "location" in the E*S plane. In Figure 1c we identify the location of three such practitioners. The point labeled "X" with values (E_{GP},S_{GP}) represents a practice or clinic staffed with a general practitioner (GP); the point labeled "Y" with values (E_{SP},S_{SP}) represents a specialist with specialist equipment; and a teleconsultation is given "Z" with values (E_{GP},S_{TM}). In this fictional example "Y" and "Z" provide the same health benefit (B_{SOC}). Consequently, they share the same iso-benefit curve despite the fact that identical quality care is delivered with different levels of skill and equipment. Note that while both points provide the same level of care they are not identical to a health care organization, since the *cost* of providing the level of care with the two different input combinations might differ dramatically. We add the cost component below.

The specific iso-benefit line associated with B_{SOC} is of particular importance to both consumers and providers. It represents the health benefit that results when a patient receives treatment for this disease commensurate with the "standard of care" as defined by the medical community[1]. This standard of care is the quality of care that the medical community considers the 'norm' for a given disease[2]

Since every clinician and/or clinic has a specific, bounded scope of practice, clinical encounters can occur for which a practitioner is ill-prepared, either in terms of skill or equipment. Conditions exist for which the GP has less equipment and/or skill than a specialist, who routinely delivers the "standard of care." For such diseases the general practitioner's health benefit falls below B_{SOC}. When such a health care disparity exists, the GP would understandably be concerned about the quality of care delivered. The concern may have two dimensions. First, the moral implications of knowingly providing inappropriate care, second the health care provider and the GP may worry about financial malpractice implications. In this situation he or she has three possible options: Retain, refer, or use teleconsultation technology. To determine which choice is relevant and efficient – both in terms of health care provision and cost minimization, we turn to a detailed discussion of costs.

III. DEFINING COST FOR EACH HEALTH BENEFIT LEVEL

From an economic point of view, one could view the provision of health benefits as a choice between costly alternatives. Greater benefits usually engender greater costs. While perfect care and maximal treatment is desirable, it is often not feasible as the financial realities of the patient or the health care provider face hard budget constraints. Hence it is of interest to find the greatest *net benefit,* one that provides a targeted health benefit that incurs the least cost[3].

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[1] There certainly exist diseases where teleconsultation cannot provide B_{SOC}, specifically those that absolutely require additional equipment. In that case the iso-benefit line is less substitutable, or more curved, with the result that Y and Z do not share the same line. In these cases teleconsultation can at best provide better care than the local provider but not the best care.

[2] Since in this economic model everything has a value associated with it, one might reasonably ask how that value for B_{SOC} can be determined. There exists a longstanding tradition for this determination that is embedded in our legal and insurance risk assessment systems. Any individual suing for malpractice is arguing that he or she did not receive B_{SOC} and that this resulted in a lost benefit. Settlements are purportedly based on the value of the health benefit that would have accrued if the standard of care had been delivered.

[3] Certainly medicine has alternative motives besides net benefit maximization. Nevertheless, this bottom line economic perspective is rapidly becoming a reality in health care today, due to budget constraints and competition. An increasing number of procedures are authorized only if the benefit derived can be justified in light of the costs incurred.

Having specified how health benefits are produced we now assume that the cost (C) of a clinical encounter for a practitioner who produces that health benefit (B) can be written as:

$$C = rE + wS + \gamma * \left(1 - B/B_{SOC}\right) + F_{\xi}$$

where: r is the cost of equipment, w is the cost of unity of medical skill, γ is the per encounter cost of insuring malpractice risk, and F_{ξ} are fixed costs specified as follows: $F_{\xi} = F_{retain} = 0$ if "Retain", $F_{\xi} = F_{travel} > 0$ if "Refer", and $F_{\xi} = F_{telec} > 0$ if "Teleconsultation"

The cost structure includes not only the direct labor and equipment costs, but also the fixed costs related to referrals (travel and time costs, for example) and teleconsultating (e.g. equipment and support cost). Costs associated with skills and equipment are variable because the health care provider can choose what level of skill and equipment to provide (and hence which level of cost to incur). Costs associated with travel are fixed, since the decision is binary, either travel is recommended and then a specific cost in incurred, or not. There is no degree of variability in those costs.

Each encounter also involves a cost of insuring against malpractice risk, which we model by including a disease specific malpractice insurance cost parameter, γ. This malpractice risk is multiplied by the probability that a malpractice suit associated with a clinical encounter is successful. The malpractice risk term acknowledges that inadequate care has financial consequences. Therefore the degree of inadequacy adds to the overall cost of such a clinical encounter. Note also that, when the delivered care is equal to the standard of care, the malpractice risk term (insurance cost times the probability to be successfully sued) in this cost equation drops to zero. In other words, whenever the standard of care has been delivered no reasonable court will assess damages. However, when the delivered care is substantially less than the accepted standard ($B \ll B_{SOC}$) the risk (and hence the cost) increases in proportion to the shortfall in health care provision.

IV. DESIGN OF ECONOMICALLY EFFIECIENT TELECONSULTATIONS

Having specified both benefits and costs, we can now examine management's decision for a health organization as to which input mix and care quality to provide at a particular clinic. Their choice is guided by two objectives: first to identify the combination of equipment and skills that produce an appropriate level of health benefit, second to provide this benefit at minimal cost. We can plot a number of health benefit lines to find an *expansion path* that traces the locus of points that represent the cost minimizing input combinations of equipment and skill for successively higher levels of health benefits. As long as the health benefit contour lines are convex to the origin (e.g., inputs are to some degree substitutable), microeconomic theory dictates that there exist only one input combination that minimizes the cost of producing a specific health benefit. The locus of these optimal points for a spectrum of iso-benefit lines is called the expansion path.

The concept of a health benefit expansion path is helpful, as it allows us to specify that any input combination that does not lie on this path must be a sub-optimal choice. Sub-optimality here implies that the mix of skills and equipment is such that slight changes in the input combination can generate either the same health benefit at lower costs, or higher health benefits at identical costs. Consequently, if a clinic's location in the E * S plane does not lie on the expansion path for a particular disease, then the input mix at that clinic can be realigned to reduce costs and maintain the same level of care. Conversely, if a health organization's management wishes to increase the health benefit of a clinic by increasing the amount of medical skills available then the expansion path also dictates an incremental increase in equipment to generate a cost effective clinical environment. The real world example would if a health care provider decides to locate a cardiologist in a GP clinic. This would not be undertaken without the appropriate equipment for the cardiology to maximize her/his health benefit provision.

This proportionality between optimal skill and equipment allocation is proven in Appendix 1, which shows that the expression for the expansion path can be rearranged such that it reveals the relationship:

$$E = \left(\frac{\alpha * w}{\beta * r} \right) * S = \phi * S$$

The equation highlights that an incremental change in equipment for each additional unit of skill depends on the relative cost of both skills and equipment (w / r) and on the relative importance of skills and equipment in treating a given disease (α / β).

The health benefit expansion path concept can also be utilized to identify clinics that are potential candidates for a referral. Since health care is an increasingly competitive market, inefficient practices or clinics will eventually terminate the provision of health care services that do not lie on the expansion path because the same service can be delivered either cheaper at other clinics, or better service can be delivered at identical cost at alternate locals. These efficient clinics lie on the expansion path X – Y in figure 1.

Teleconsultations are also constrained to a specific locus of points in the E*S plane (e.g. the line drawn between "X" and "Z" in figure 1). This is because teleconsultations represent a combination of the equipment that can locally interface with the patient and a distant specialist's skill. Equipment that cannot directly interface with the patient during the clinical encounter is of no consequence. For example, the MRI at the specialist clinic is of no value if the patient is 900 miles distant. Hence, the office in which the patient is present defines the equipment that can be brought to bear in telemedicine. In most cases this equipment is designed only to complement the GP. Below we will show that this is not necessarily cost efficient under telemedicine. The locus of possible teleconsultations can thus be defined by the line $E = E_{GP}$ for all S (e.g. $E_{TeleC} = E_{GP}$ for all levels of S_{TeleC}).

V. TELECONSULTATION VS. REFERRAL

Let us assume that a health organization's management has successfully positioned its clinics and is now considering acquisition of teleconsultation equipment to gain competitive advantage by providing better health care at lower cost. How should clinics be outfitted (in terms of equipment and skill) and what guidance should they give to their providers concerning the use of this technology?

To answer these questions we begin by assuming that a distant specialist (e.g. "Y" in figure 1) is able to accept either a referral or to provide teleconsultation. How much will the patient's health benefit increase using teleconsultation (e.g. B_{TeleC}) or referral (e.g. B_{Refer}), and under what conditions will the telehealth consultation have benefits that roughly equate to those received through face to face interaction with the specialist?

To answer this question we utilize the health benefit function and apply it to each possible disease scenario, refer, retain or teleconsult, to derive specific health benefit indices. To compare the relative effectiveness of referrals, teleconsultations or retaining a patient we introduce three relative health benefit indices. First we define the *Teleconsult Benefit Index,* Ω_T as the ratio of the health benefits associated with teleconsultation (B_{TeleC}) to those a general practitioner can supply (B_{Retain}):

$$\Omega_T \equiv \frac{B_{TeleC}}{B_{\text{Re}tain}} = \frac{AE_{GP}^{\alpha} S_{SP}^{\beta}}{AE_{GP}^{\alpha} S_{GP}^{\beta}} = \left(\frac{S_{SP}}{S_{GP}}\right)^{\beta}$$

The greater the index the higher the relative health benefit derived from a Teleconsultation. The index suggests that, for the diseases where skills are basically irrelevant to the provision of health benefits (e.g., dialysis), there exists little incremental health benefit associated with using teleconsultation to bring in a specialist. This is the case where $\beta \cong 0$, $\Omega_{TB} = 1$, resulting in $B_{TeleC} \cong B_{Retain}$. Conversely, the index also reveals that when skills are crucial for the provision of health benefits of a specific disease, the increase in health benefits by using teleconsultations is approximately equal to the practitioners' skill ratio. This is the case where β is large, resulting in $B_{TeleC} \cong (S_{SP}/S_{GP})^* B_{Retain}$.

The same technique allows us to derive a *Referral Benefit Index* , Ω_R

$$\Omega_R \equiv \frac{B_{\text{Re}fer}}{B_{\text{Re}tain}} = \frac{AE_{SP}^{\alpha} S_{SP}^{\beta}}{AE_{GP}^{\alpha} S_{GP}^{\beta}} = \left(\frac{E_{SP}}{E_{GP}}\right)^{\alpha}\left(\frac{S_{SP}}{S_{GP}}\right)^{\beta}$$

where higher values of Ω_R now indicate greater relative benefits to referrals. A referral implies that patients benefit not only from a better skilled provider (as in the case of teleconsultation), but also from potentially additional equipment at the specialist's locale. Therefore the Ω_R depends not only on the importance of practitioners skills (β), but also on the importance of equipment in the generation of health benefits (α).

Finally we derive a *Realtive Teleconsult Efficacy Index*, Ω_{TE} which measures the extent to which a teleconsult approximates the benefit received by direct patient contact with the specialist[4].

$$\Omega_{TE} = \frac{B_{TleleC}}{B_{\text{Re}\,fer}} = \frac{AE_{GP}^{\alpha} S_{SP}^{\beta}}{AE_{SP}^{\alpha} S_{SP}^{\beta}} = \left(\frac{E_{GP}}{E_{SP}}\right)^{\alpha}$$

Since the only advantage that a referral generates over teleconsultation is that it allows the patient access to the specialist's equipment, Ω_{TE} depends both upon the relative equipment levels as well as the relative effectiveness of the equipment that is employed. When equipment is irrelevant to the treatment, $\alpha \cong 0$, teleconsultation is nearly as efficacious as a referral since , $\Omega_{TE} \cong 1$ which implies $B_{TeleC} \cong B_{Refer}$. Conversely for α large, the health benefit from consultation will be less than that for referral with $B_{TeleC} \cong (E_{GP}/E_{SP})^* B_{Retain.}$ In this case the Ω_{TE} declines as the equpment discrepancy between the general practitioner and the and specialist increases..

These three indices define the characteristics (e.g. α and β) of medical conditions for which teleconsultation can generate health benefits that are roughly equivalent to those of a referral. As such, they could provide managers and policy makers with guidance concerning the diseases that should be considered for teleconsulting support and technology. The final decision, however, if teleconsultations should be instituted, depends on the relation between the gained benefit relative to the incurred cost.

For the benefit/cost comparison it is crucially important to recall that teleconsultation health benefits can never exceed those generated by an optimal referral. Hence teleconsultation will only be employed when its use represents a financial advantage for a given health benefit level. Algebraically, the condition that teleconsultation is preferred to an alternative (e.g. retain or refer) can be derived by examining the associated costs for each health benefit alternative. For example, a positive cost differential (C_{TeleC} - C_{Retain}) > 0 indicates that a teleconsultation would be

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[4] In the derivation we have utilized the fact that an efficient telehealth consultation provides access to all of the specialist's skills, implying $(S_{TeleC} = S_{SP})$.

preferred financially (not necessarily medically) to retaining the patient. Writing the costs explicitly, teleconsultation dominates retention whenever

$$\underbrace{\left[rE_{GP} + wS_{SP} + \gamma * \left(1 - {B_{TeleC}}/{B_{SOC}}\right) + F_{TeleC}\right]}_{\text{TeleConsultation cost}} - \underbrace{\left[rE_{GP} + wS_{GP} + \gamma * \left(1 - {B_{Retain}}/{B_{SOC}}\right)\right]}_{\text{Retain cost}} < 0$$

Uniting the concepts of both benefits and costs into one analysis, we utilize the concept that health care providers strive to achieve the "standard of care" health benefit, then $B_{Refer} = B_{SOC}$. Under this condition we can substitute health benefits into the cost analysis and rearrange the net cost condition to find that teleconsultation dominates retention whenever

$$\underbrace{\gamma * \Omega_{TE} * \left(1 - \Omega_T^{-1}\right)}_{Malpractice\ Premium} > \underbrace{w\left(S_{SP} - S_{GP}\right)}_{Skills\ Premium} + \underbrace{\left(F_{TeleC}\right)}_{Cost\ Premium}, \text{ or}$$

$$\underbrace{\gamma * \left(\frac{E_{GP}}{E_{SP}}\right)^{\alpha} * \left(1 - \left(\frac{S_{GP}}{S_{SP}}\right)^{\beta}\right)}_{Malpractice\ Premium} > \underbrace{w\left(S_{SP} - S_{GP}\right)}_{Skills\ Premium} + \underbrace{\left(F_{TeleC}\right)}_{Cost\ Premium}$$

Notice that teleconsultations are becoming the more efficient option and hence more likely in the real world when a) the GP vs. specialist skill differential rises, or when the GP vs specialist equipment differential declines. It is widely known that teleconsultations are efficient if the provide access to specialists. Here we show that they will also become more prevalent when the GP is provided with more equipment that the specialist may use in the teleconsult!

Using the same assumption regarding $B_{Refer} = B_{SOC}$ we show that teleconsulting will dominate referral when

$$\underbrace{\gamma * \left(1 - \Omega_{TE}\right)}_{Malpractice\ Premium} < \underbrace{r\left(E_{SP} - E_{GP}\right)}_{Equipment\ Premium} + \underbrace{\left(C_{Travel} - C_{TeleC}\right)}_{Cost\ Premium}, \text{or}$$

$$\underbrace{\gamma * \left(1 - \left(\frac{E_{GP}}{E_{SP}}\right)^{\alpha}\right)}_{Malpractice\ Premium} < \underbrace{r\left(E_{SP} - E_{GP}\right)}_{Equipment\ Premium} + \underbrace{\left(C_{Travel} - C_{TeleC}\right)}_{Cost\ Premium}$$

Note that the referral decision only a function of equipment (and fixed costs, which the health care organization cannot influence). Skills are irrelevant, since teleconsultations provide equal access. The larger the equipment differential the more likely the right hand side becomes.

The specific conditions under which teleconsultation becomes the cost minimizing choice, *for a given level of appropriate health benefit* are therefore defined by two algebraic statements. In both cases the issue is the relationship between the malpractice premium and incremental additional costs incurred. Teleconsultation is preferred to retention when the malpractice premium associated with retaining the patient exceeds the skills premium and the fixed costs of the telecomunications equipment. On the other hand, teleconsultation is only then preferred to referral when the malpractice premium associated with a teleconsulation versus referral comparision[5] is less than the additional cost of referral (e.g. equipment premium in addition to the skills premium charged in both teleconsultation and referral) and the extent to which the travel costs exceed the equipment cost.

VI. DISCUSSION

We employ microeconomic principles to analyze the decision by health managers and policy makers to acquire and utilize telehealth consultation technologies. The model highlights that whenever a health care provider cannot generate a standard health benefit, $B < B_{SOC}$, the provider must weigh the cost of increased malpractice risk versus the added costs of a referral. The analysis presented in this paper maps cost and disease characteristics into a decision matrix health managers can use to minimize costs at a given health benefit by adding teleconsultation as an available alternative to referral. Crucially, the analysis debunks the common notion that teleconsultation is a simple comparison between the travel costs of referrals vs. communications costs incurred by teleconsult technologies.

A subtler point of the analysis is that the equipment differential between the general practitioner and the specialist itself should be endogenous *when teleconsultation*

[5] e.g. the extent to which this approach does not reach the B_{SOC} health benefit that would be generated by a referral.

becomes an option. When a health organization implements telehealth consulting as an additional option, it then makes sense to provide the general practitioner with equipment that can be used by a specialist during a telehealth consultation. Our teleconsult efficacy index shows that this would narrow the equipment premium and thus increase the chance that teleconsultation can be a financially efficient alternative.

It is also important to note that the model presented in this paper has found wide acceptance in across manufacturing industries. It is, however, only a model and as such provides a general blueprint for testable implications without assurances that it reflects all features of the health care sector.

Economic frameworks typically make assumptions that simplify the real world into a model to illustrate insights. When it comes to the health delivery system these simplifying assumptions may be difficult to accept; nevertheless the modeling approach can be chosen to highlight insights that pertain to a particular aspect of a problem that requires analysis. So, for example an assumption that consumers have complete knowledge of a product's value may be acceptable for the sake of a stock transaction on the New York Stock Exchange, but may be called into question in the context of health care decisions. In this paper we introduce strong assumptions to transparently illuminate a particular aspect of the real world. The insights derived from our model are not sensitive to the assumptions we made, however our results may be augmented as we introduce additional complexity.

Empirical research is necessary to indicate how relevant our assumptions and results are to the health care environment. Models such as the health care benefit and cost function we proposed above have been estimated widely in the economics profession. When needed, the model can be extended in multiple dimensions, for example to include consumer uncertainty as to the value of the health product, or to include the “disconnect” between payer and consumer. Research concerning the validity of the production function approach in the realm of health economics, as well as the determination of disease specific parameters, and the appropriateness of assumptions concerning market forces and the expansion path, as well as consideration of alternative cost estimating equations must precede any acceptance of the model as a viable tool for teleconsultation decision makers. Still, in its present form the model makes specific predictions that have face validity.

If the model is validated then the specification of these conditions can serve as a policy guideline for decision makers who must decide if and how teleconsultation applications should be implemented into the clinical environment.

APPENDIX

Let the production function be defined as $R = B/B_{SOC} = AE^{\alpha}S^{\beta}$, then

$$\frac{\partial R}{\partial E} = A\alpha\, E^{\alpha-1}S^{\beta} = \frac{A\alpha\, E^{\alpha}S^{\beta}}{E} = \frac{\alpha\, R}{E}\, and\, \frac{\partial R}{\partial S} = A\beta\, E^{\alpha}S^{\beta-1} = \frac{A\beta\, E^{\alpha}S^{\beta}}{S} = \frac{\beta\, R}{S}$$

Similarly, if the cost is defined as $C = rE + wS + \gamma(1-R) + C_{\xi}$, then

$$\frac{\partial C}{\partial E} = r - \gamma\frac{\partial R}{\partial E}\, and\, \frac{\partial C}{\partial S} = w - \gamma\frac{\partial R}{\partial S}$$

The expansion path is then the locus of points for which:

$$\frac{\partial C}{\partial E} = \frac{\partial R}{\partial E} \qquad \& \qquad \frac{\partial C}{\partial S} = \frac{\partial R}{\partial S}$$. Hence $\frac{\partial C/\partial S}{\partial C/\partial E} = \frac{\partial R/\partial S}{\partial R/\partial E}$ and

$$\frac{\left[\omega - \gamma\left(\frac{\beta\, R}{S}\right)\right]}{\left[r - \gamma\left(\frac{\alpha\, R}{E}\right)\right]} = \frac{\left(\frac{\beta\, R}{S}\right)}{\left(\frac{\alpha\, R}{E}\right)} = \frac{E\beta}{S\alpha}$$, where $S\alpha\left[\omega - \gamma\left(\frac{\beta\, R}{S}\right)\right] = E\beta\left[\omega - \gamma\left(\frac{\beta\, R}{S}\right)\right]$

This leads to the expansion path given by: $E = \left[(\alpha * w)/(\beta * r)\right] * S = \phi * S$

Figure 1a
Benefit of Consultant's Knowledge

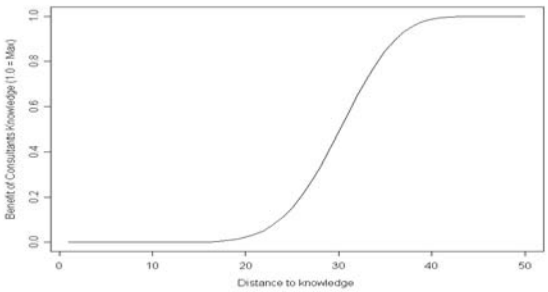


Figure 1b
Cost of Required Equipment

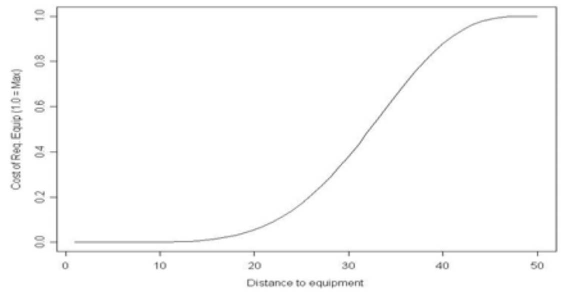
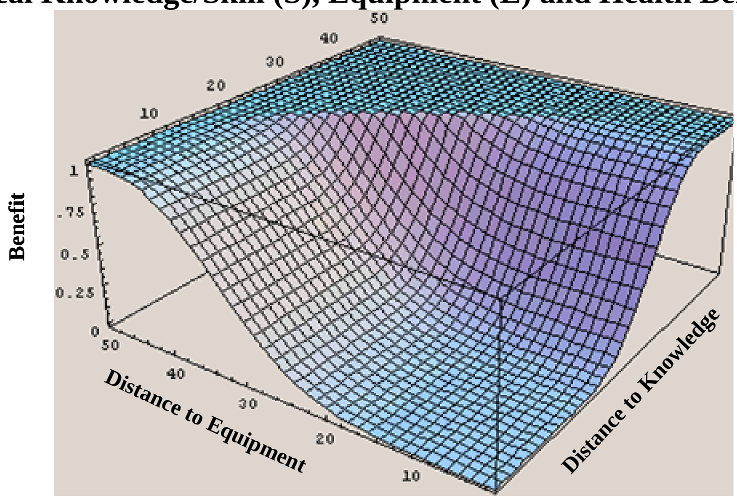


Figure 1c
Medical Knowledge/Skill (S), Equipment (E) and Health Benefit



Note: Figures 1a and 1b combined in 3 dimensions

Figure 2
Benefit of Referral

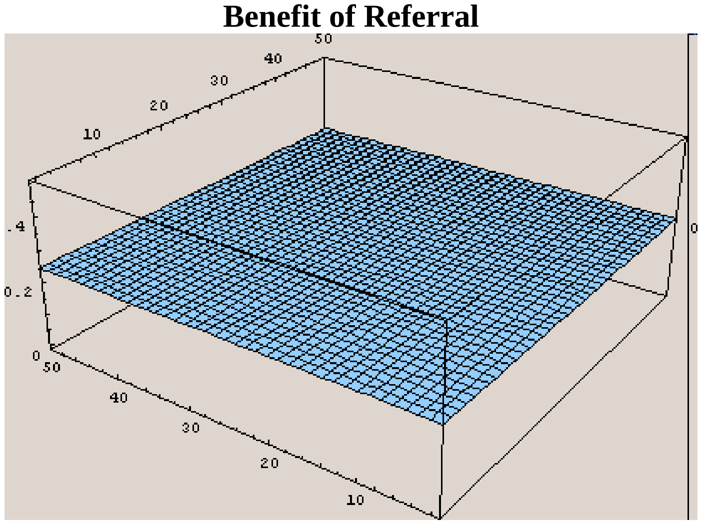


Figure 3
Intersection of Referral Costs and Medical Benefits

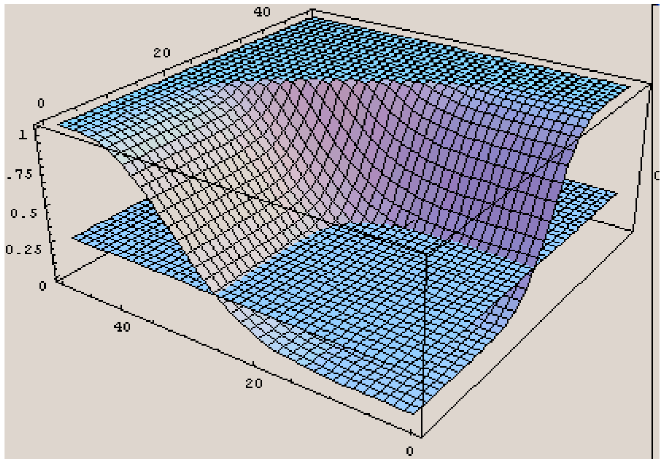


Figure 4

Figure 2 as viewed from above | **Decision Frontiers (no Telehealth)**

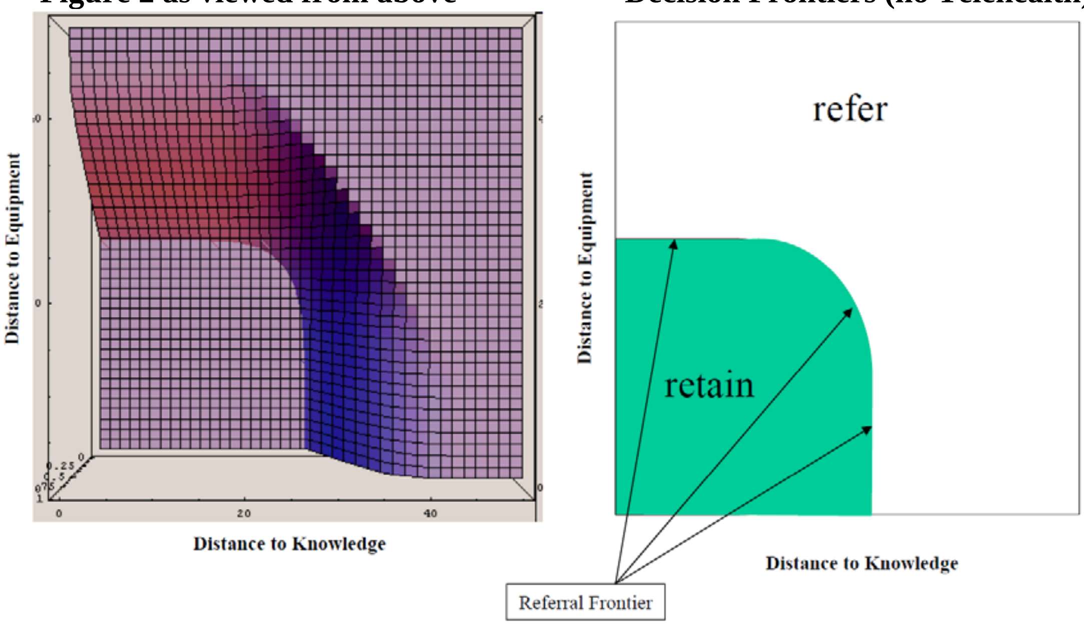
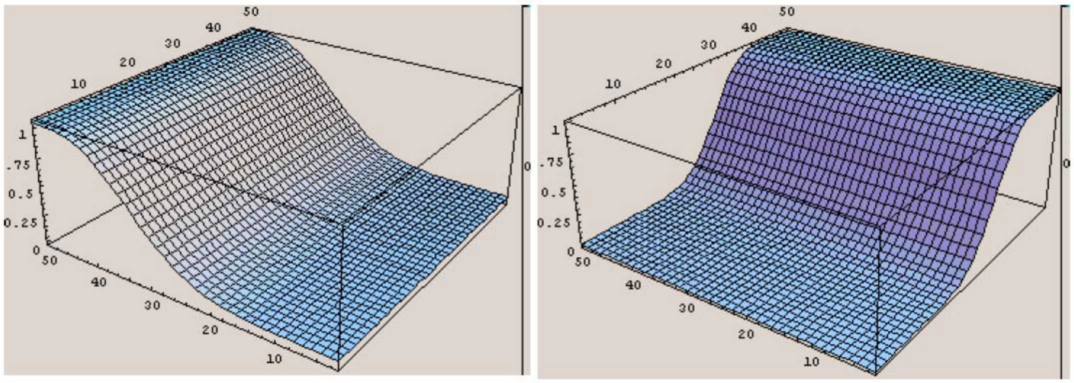


Figure 5
Introducing Telehealth



Costs Benefits

Figure 6
Intersection of Referral Costs and Medical Benefits With Telehealth

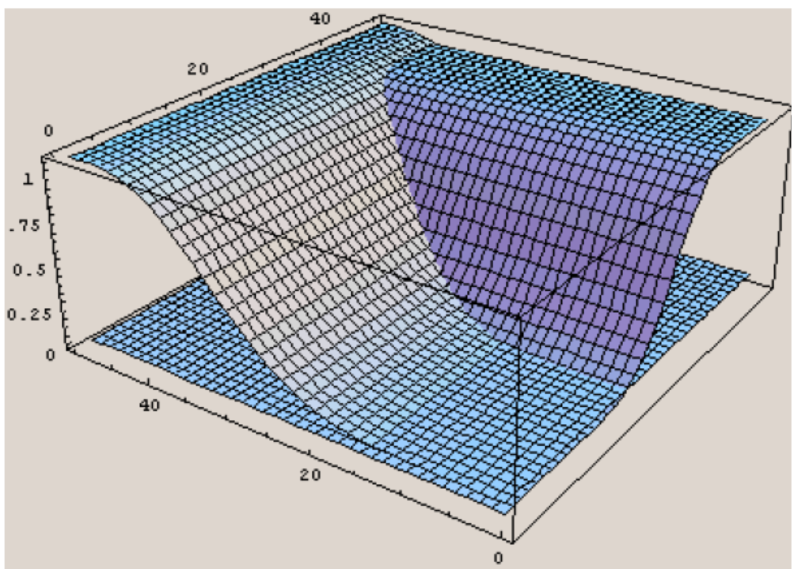
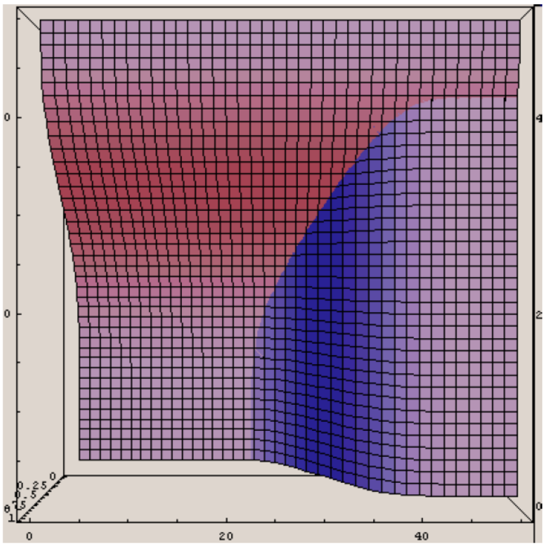


Figure 7

Figure 6 as viewed from above **Telehealth Decision Frontier**



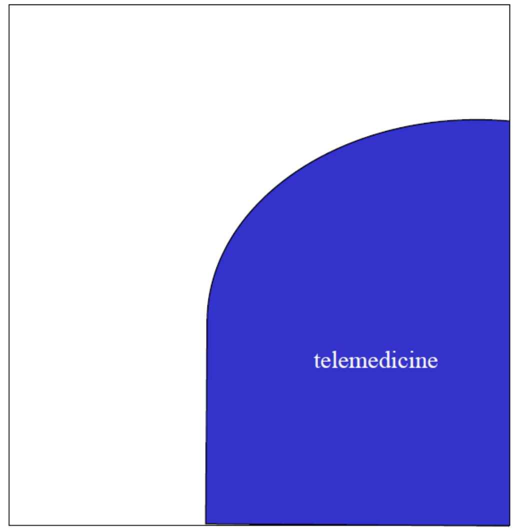


Figure 8
Decision Frontiers Retain-Refer-Telemedicin