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Optimum Investments in Project Evaluations: When Are Cost-Effectiveness Analyses Cost-Effective?

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This manuscript extends the classical models of the value of information to ask whether a hospital's net financial return is ever maximized by a cost-effectiveness analysis of retrospective data when watchful waiting and a full randomized clinical trial are alternative methodologies. The manuscript demonstrates that (1) some small-scale retrospective analyses may negatively affect net income and (2) under some conditions, larger-scale retrospective analyses may maximize net income. The manuscript also suggests that risk aversion increases the value of information and therefore the optimum expenditure on a project evaluation.

KEY WORDS: Cost-effectiveness; project evaluation; risk aversion.

INTRODUCTION

The attributes of well-designed clinical trials,[1] technology evaluations,[2,3] and cost-effectiveness analyses[4] are well-known. Yet the rigorous evaluations described in these and other references may be more expensive than can be justified by their benefits.[5,6]. Especially for a single institution, the cash flow improvements expected from the evaluation of a single project may not be sufficiently large to justify the financial resources required by a thorough study.

In fact, health care executives will often spend nothing on project evaluations when they expect sufficient information from "watchful waiting." Existing management information systems and the passage of time do provide information about a project's success or failure without any additional expenditures on evaluations.

While the theoretical foundations for quasi-experimental research designs using retrospective data have been laid,[7] the management tools to understand production variations have been well-explained,[8] and the value of risk-reducing informa-

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tion has been introduced,[9] there is less than perfect understanding about when these approaches should be applied.[10]. Statistical analyses of retrospective data typically provide intermediate amounts of information and require intermediate evaluation expenditures. The question is when, if ever, these analyses are financially superior to "watchful waiting" or randomized clinical trials.

This manuscript first models the benefits and costs of project evaluations to an income maximizing, risk neutral institution. In this context, the characteristics of projects that justify no more than "watchful waiting" are distinguished from those requiring a randomized clinical trial. Importantly, the model demonstrates that some projects are optimally evaluated with intermediate assessments. Because a properly specified retrospective analysis may be relatively inexpensive compared to the information it yields, it may be a better investment than either a randomized clinical trial or "watchful waiting."

Second, the manuscript models the benefits and costs of project evaluations to an income maximizing, risk averse institution. Because project evaluations act to reduce the uncertainty about project outcomes, risk aversion considerations act to increase the optimum evaluation expenditure.

CLASSICAL MODEL OF THE VALUE OF INFORMATION

Consider an institution faced with deciding how much to spend evaluating a project designed to increase income. The evaluation may be valuable to the extent that it identifies the project's failure more rapidly than "watchful waiting" and, as a consequence, allows the institution to cut losses off more quickly.

In a classical characterization of decisions under uncertainty, consider the hypothetical 2 × 2 payoff matrix of Table I in which the rows indicate whether or not the project is to be continued, the columns correspond to two possible profitability scenarios, and the four cells contain the net present value of the hospital's income assuming no evaluation expenditures. In this hypothetical payoff matrix, continuing the project is riskier because its values ($100 and –$40) lie outside the range ($20 and –$8) of discontinuing the project.

Note that while these figures represent a net present value of income over time without information from an evaluation, the model assumes that institutions do have some management and financial information system that will eventually provide sufficient information to determine the project's success or failure. Thus the –$40 represents the net present value of the loss that would be incurred if the unsuccessful project were continued until existing information systems indicated a failure strongly enough to terminate the project.

Table I. Payoff Matrix—Hospital Income

Probabilities	I: Program Successful 50%	II: Program Failure 50%	Expected Income
A: Continue program	100	–40	30
B: End program	20	–8	6

We describe this reliance on existing information systems as "watchful waiting" and note that it defines a baseline or starting point against which the costs and benefits of a project evaluation are measured incrementally. Of course, the benefits of project evaluations are greater in institutions with relatively weak information systems. Conversely, the potential savings from eliminating frequent and costly project evaluations serve as one justification for more expensive information systems.

If estimated probability values associated with the project's success or failure are available, then the risk neutral institution should continue or stop the project according to the greatest expected income. To illustrate, initially assume that the two scenarios have equal probabilities. In this context, the institution should continue the project because its expected income ($30) is greater than the income ($6) if the project is halted.

The notion of perfect information refers to perfect knowledge of the project's success or failure prior to having to decide about its continuation. By having that knowledge, the institution can choose the alternative yielding the maximum income for the given state of nature. For our example, the optimum alternative and associated income value for each state of nature are reported in Table II.

The expected income under perfect information is calculated by applying probabilities to these maximal values for each scenario. For the probabilities assumed in our example, this expected income is $46. Thus the perfect information increases our expected income from $30 to $46. This $16 difference is the expected value of perfect information. If the project evaluation were the source of perfect information, classical decision theory would suggest that a hospital pay no more than $16 for the evaluation.

While these results measure the value of perfect information in reducing uncertainty, they give the institution little insight into the optimum expenditures on project evaluation. The following sections discuss the concept of imperfect information, model the value of such information, analyze the optimal evaluation given an increasing cost function, and consider the effects of managerial risk aversion.

VALUE OF IMPERFECT INFORMATION

This manuscript focuses attention on the potential value of imperfect information. By definition, imperfect information has a nonzero probability of reporting the incorrect status of the project's success or failure. While the information content of different posterior distributions can be measured in several ways,[11] this manu-

Table II. Hospital Income with Perfect Information

	I: Program Successful	II: Program Failure	Expected Income w/Perf. info.
Optimal decision	Continue	End	
Net income with optimal decision	100	-8	
Probability of program outcome	50%	50%	
Expected income	50	-4	46

Table III. Payoff Matrixes under Imperfect Information

A. Evaluation Predcits a Successful Project

	Project Successful	Project Failed	Expected Income
Posterior prob.	75%	25%	
Continue proj.	100	-40	65
End proj.	20	-8	13

B. Evaluation Predicts a Failed Project

	Project Successful	Project Failed	Expected Income
Posterior prob.	25%	75%	
Continue proj.	100	-40	-5
End proj.	20	-8	-1

script's purposes are met by the simplest. Under the assumption that the evaluations will correctly report success or failure with equal probability, the posterior probability of the project's success given an evaluation indicating success is one measure of information gained from the evaluation. Relaxing this assumption complicates the mathematics without generating additional results.

To illustrate the effects of imperfect information, consider a less than perfect project evaluation. Suppose that if this evaluation indicated a successful project, the actual probability of success would only increase from 50% to 75% as illustrated in Table III. Similarly, assume that when the evaluation indicates a failure, the project actually fails with the probability of 75%. With this level of information and an evaluation indicating success, the institution would continue the project and expect an income of $65. If the same evaluation indicated failure, the institution should stop the project and expect an income of –$1.

The probability that Success will be predicted is:

$$\begin{aligned}&\text{P(Predicted Success)}\\&\quad \text{P(Pred. Success} \mid \text{Success Occurs)} * \text{P(Success Occurs)}\\&\qquad + \text{P(Pred.Success} \mid \text{Failure Occurs)} * \text{P(Failure Occurs)}\\&\quad = (.75 * .50) + (.25 * .50) = .50\end{aligned}$$

The probability that a Failed Project will be predicted is similarly calculated as .50.

The expected income from such an evaluation is:

$$\begin{aligned}&\text{Expected Income} \mid \text{Evaluation}\\&\quad = (\text{Expected Income} \mid \text{Pred. Success}) * \text{P(Pred.Success)}\\&\qquad + (\text{Expected Income} \mid \text{Pred. Failure}) * \text{P(Pred. Failure)}\\&\quad = (\$65 * .5) + (-\$1 * .5) = \$32\end{aligned}$$

Consequently, this evaluation increased expected income by $2 ($32-$30).

But note that not all evaluations increase income, as shown in Fig. 1. As will be shown for this model, evaluations which increase the posterior probability to 71% or less have no impact on income and therefore have no benefit. This occurs because evaluations which provide such limited information don't change the institution's decision. The project will be continued regardless of the evaluation's results

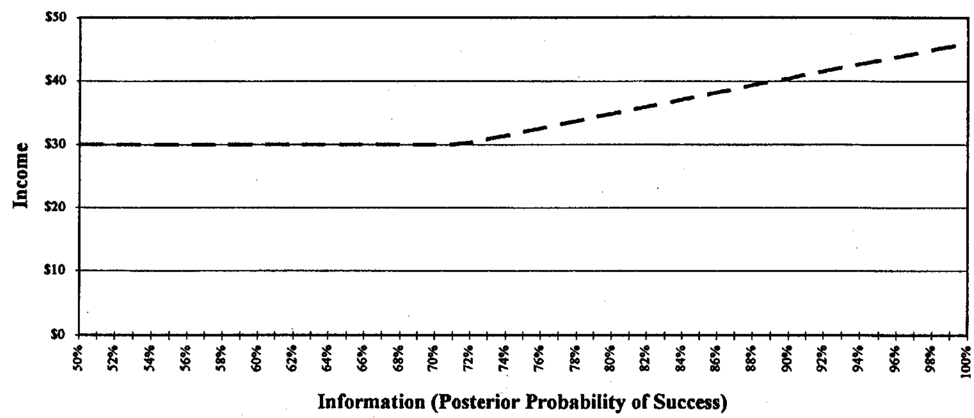

Fig. 1. Income between no and perfect information.

regarding success or failure. The evaluation only increases income if the evaluation is sufficiently accurate to lead the institution to actually stop the project and cut its operational losses in the case of a predicted failure.

OPTIMAL EVALUATION EXPENDITURE

While the classical model indicates the value of information and therefore the breakeven amount that could be spent on an evaluation, it does not determine the optimum evaluation expenditure. The optimum evaluation expenditure is that outlay which maximizes the institution's expected net income after evaluation expenditures.

The preceding computation of Expected Income | Evaluation can be generalized. Let I denote the information measured by the posterior probabilities ($.5 \leq I \leq 1$). That is, I equals the probability that the evaluation reports the correct state of the project. Then, when the evaluation predicts a successful project and the project is continued, the expected income will equal:

$$100*I-40*(1-I) = 140*I-40.$$

Similarly, when the evaluation predicts a failed project and the project is ended, the expected income will equal.

$$20*(1-I)-8*I = -28*I + 20.$$

Then the Expected Income | Evaluation is simply the average of these two quantities or:

$$0.5*(140*I-40) + 0.5*(-28*I + 20) = 56*I-10.$$

If one decides to continue the project without regard to the results of an evaluation, the expected income is given by:

$$0.5*(100*I-40*(1-I)) + 0.5*(100*(1-I)-40*I) = 30.$$

Thus, the evaluation results will be used according to whether 30 or $56*I-10$ is larger, so that

$$\text{NETINCOME} = \max[30, 56*I-10].$$

In this example, relatively small amounts of information provide no net income above the $30 expected before any evaluation. In this model at amounts of information above 71%, net income increases linearly according to the second term in the equation.

Furthermore, assume that the evaluation costs are an increasing function of information. By definition, no evaluation means no evaluation cost. By assumption, the simpler evaluations require much smaller outlays for the information they generate than the full blown clinical trials. While randomized clinical trials may produce almost perfect information, they are extremely expensive. As an example, consider the following increasing and convex cost function:

$$\text{Evaluation Cost} = 144*(I-.5)^3$$

The optimum evaluation expenditure is defined as that evaluation outlay that generates the maximum difference between the income expected from the project and the costs of its evaluation. In the illustration developed above, this net income maximization of $31.44 occurs at $I = .86$, at the point where the slope of the income curve just equals the slope of the cost curve (Fig. 2).

While the example developed in the text illustrates an intermediate evaluation, it is obviously a special case. "Watchful waiting" without an evaluation would be optimal if the incremental costs of the evaluation were higher than any additional income generated by the incremental information. Alternatively, if additional information generated higher income than the cost of perfect information, a full blown randomized clinical trial would be optimal. All the model and its illustration have demonstrated is that an intermediate evaluation, such as a retrospective cost-effectiveness analysis, can be optimal under some circumstances.

OPTIMUM EVALUATION EXPENDITURES WITH RISK AVERSION

If the hospital's objectives are expanded to include both increasing net income and reducing risk, the relative riskiness of continuing the project reduces its value and increases the effective value of perfect information.

Finance and economics textbooks[12] often represent risk averse preferences with a diminishing marginal utility of income. In such cases, utility increases with income, but less rapidly with increasing levels of income. Consider as an example:

$$U = (5 * \text{NETINCOME})-(\text{NETINCOME}^2)/45$$

Application of this utility function to the Payoff Matrix in Table I yields the matrix of utilities of Table IV. Whereas the higher expected income of continuing the project would lead the risk neutral institution to continue the project, a risk

Table IV. Payoff Matrix—Utilities

Probabilities	I: Program Successful 50%	II: Program Failure 50%	Expected Utility
A: Continue program	277.78	−235.56	21.11
B: End program	91.11	−41.42	24.84

averse institution with this utility function would be so averse to the uncertainty of being successful that its utility would be maximized ($U = 24.84$) by stopping it.

The utility value of perfect information is calculated exactly as with its impact on income. If the institution knows that the Program will be successful, it should continue the program, yielding a utility of 277.78. If the institution knows the Program will be unsuccessful, it should end it yielding a utility of −41.42. Application of the 50-50 probability for the scenarios gives an expected utility of 118.18, a utility increase of 93.33 attributable to perfect information.

More importantly, risk averse institutions attach a greater value to project evaluations than do risk neutral individuals. First, risk averters gain utility from evaluations which reduce uncertainty without increasing income. Applying utility to the uncertain information developed above, utility increases result from evaluations which increase the posterior probability to 52 or more percent (Fig. 3). Income increases aren't realized until the probability is above 71% (Fig. 2).

It is important to note that the utility of the difference between income and evaluation costs can not be determined by the difference between the income's utility and the evaluation cost's utility. This follows from the fact that the utility function is not linear; only when two operators are linear can the operations be interchanged. Thus, the utility function must be applied to each possible net income (income minus evaluation expense), and the probabilities can be applied to calculate expected utilities.

Second, risk averse hospitals will tend to optimize their evaluation expenditures at higher information levels than will risk neutral institutions. Optimum evaluations for risk averse institutions occur at the evaluation with the highest expected utility

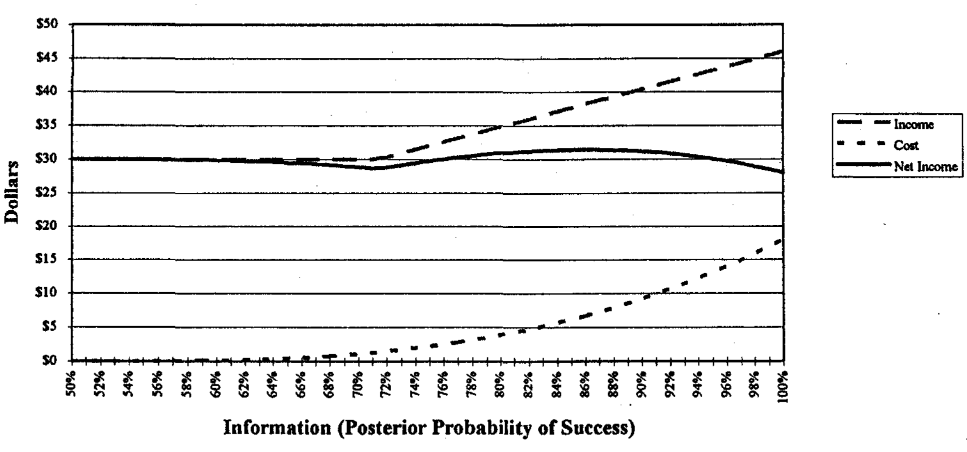

Fig. 2. Net income from information.

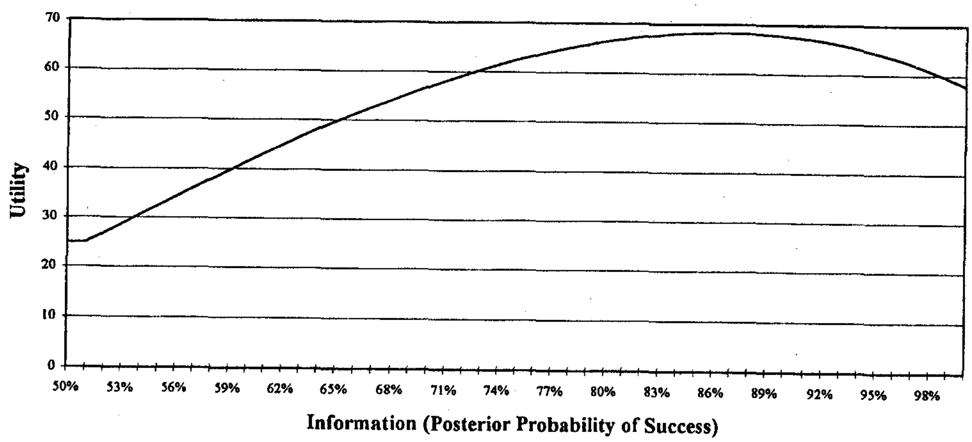

Fig. 3. Expected utility from net income after evaluation costs.

calculated on after-evaluation-expense incomes. In this illustration, utility is maximized at $I = .88$, which is 2% more information and $.016 lower net income than would be selected by risk neutral institutions. The higher information and lower expected net income combination is optimal because the greater information reduces risk, and as a consequence increases utility, by enough to offset the utility loss from lower net income.

DISCUSSION

This manuscript develops a model which demonstrates the potential optimality of intermediate expenditures on project evaluations. Clearly, there are projects for which simple "watchful waiting" or thorough randomized clinical trials may be appropriate. This manuscript simply notes that there may also be projects for which the optimal evaluation would be an intermediate effort, such as a statistical analysis of retrospectively collected data about the project's benefits and costs. In other words, the manuscript has only demonstrated that such cost-effectiveness evaluations at least may themselves be cost-effective in certain situations.

In the context of a relatively simple model of decision under uncertainty, several factors appear to increase the likelihood that an intermediate project evaluation will be optimal. These include (1) risk aversion as we have defined it, (2) relatively low costs of the initial units of information and then rapid increases which make near perfect information prohibitively expensive, and (3) at least one evaluation option which provides substantial information. Factors which decrease the likelihood of an intermediate solution include (1) risk neutrality, (2) either very high evaluation costs relative to the project benefits or very high benefits relative to evaluation costs, and (3) a superior executive and financial information system with capabilities of identifying project outcomes within routine reports.

While this manuscript makes no summary recommendation about optimum evaluation expenditure levels, it does imply that the level of evaluation expenditures is an important issue. Spending too much or too little on the project evaluation generates unnecessarily high administrative costs and may be a greater waste of money than over-or under-spending on health care itself. While the suboptimality of excessively high expenditures on health care are blunted by the additional benefits received by patients, excessively high expenditures on evaluations bring absolutely no marginal benefits to patients.

Finally, any decision about the level of project evaluation expenditures obviously should be made as an integral part of design of the project itself. Once a project is implemented, randomization and concurrent data collection required by clinical trials become impossible. And in some cases where evaluation decisions are postponed beyond implementation, data acquisition costs may be substantially increased and the information content reduced if the facts necessary for retrospective analyses are themselves collected months or years later.

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