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THESIS

DISCOUNTING IN MILITARY  
COST-EFFECTIVENESS STUDIES

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DONALD R. STONE

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COST-EFFECTIVENESS STUDIES

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DONALD R. STONE

DISCOUNTING IN MILITARY  
COST-EFFECTIVENESS STUDIES

by

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Lieutenant, Supply Corps  
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Submitted in partial fulfillment of  
the requirements for the degree of

MASTER OF SCIENCE  
IN  
OPERATIONS RESEARCH

United States Naval Postgraduate School  
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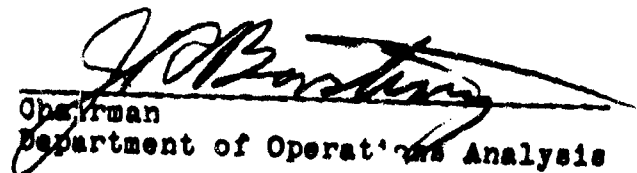
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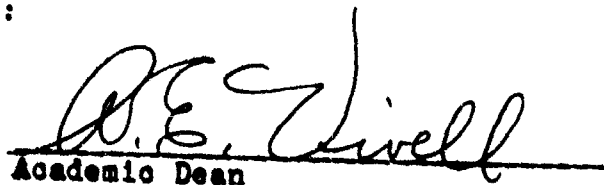


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## ABSTRACT

Discounting is a means of assigning different weights to costs expected to be incurred in different future time periods. Such costs are a vital element of cost-effectiveness studies, which under present Department of Defense policy provide the primary basis for military procurement and force structure decision making.

The discounting process is reviewed, and an attempt is made to identify qualitatively the factors which should determine the discount rate to be used in Department of Defense cost-effectiveness studies. These factors are separated into two groups: those which apply to cost-effectiveness studies of all types of weapons systems, and those which depend upon the type of system being considered.

Finally the manner of presenting the results of the discounting process to the decisionmaker is discussed.

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1. Introduction.

The technique of discounting future costs and benefits in order to obtain their present values is an accepted method of converting a multiperiod problem to a static problem in economic investment theory.<sup>1</sup> The private firm in a market economy is assumed to be a profit maximizer; i.e., to act so as to maximize the difference between revenues and costs, where both are measured in dollars. When investments which involve revenues and costs occurring in dissimilar time periods are being considered, the firm should invest in such a way as to maximize the difference between the present values of future revenues and costs.<sup>2</sup> Discounting is the technique used to obtain these present values of future revenues and costs.<sup>3</sup>

In government operations, and in particular in Department of Defense operations, similar investment allocation problems arise during the formulation of procurement policies and the planning of future force compositions. Although the discounting procedure is still applicable, important complications are introduced by the absence of a marketplace for government output. Perhaps the most serious practical difficulty introduced is that government

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<sup>1</sup>Roland N. McKean, Efficiency in Government through Systems Analysis (New York: John Wiley and Sons, Inc., 1958), 76.

<sup>2</sup>Ibid.

<sup>3</sup>Ibid., 76-78.

returns cannot be measured directly as dollar revenues from sales. A related difficulty is the determination of the discount rate to be used in present value calculations. This paper is concerned with the latter problem.

## 2. Cost-Effectiveness Studies.

Before a proper discount rate can be determined it is necessary to describe the investment action being contemplated. To a large extent current major Defense Department decisions, including investment decisions, are made on the basis of systems analyses.<sup>1</sup> Systems analyses are analytical studies of alternative means of accomplishing some Defense Department objective. These objectives are usually attained through employment of one or more weapons systems.<sup>2</sup>

As used here, a weapons system is defined as the primary equipment needed to perform a certain mission, plus all of the men, facilities, and equipment required for its utilization and support. As an example consider an underwater-launched medium range ballistic missile system. Here the defense objective might be the ability to retaliate against an enemy who attacks first, and by possessing this capability to deter such an enemy attack. The capability

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<sup>1</sup>Statement made by Dr. Alain C. Enthoven, Deputy Assistant Secretary of Defense (Systems Analysis), in an address to the student body of the U. S. Naval Postgraduate School, Monterey, California, 17 February, 1965.

<sup>2</sup>The term "systems analysis" is not precisely defined in the literature. Synonymous terms in different applications are operations research, systems research, systems design, systems engineering, management science, and cost-effectiveness analysis. See RAND Corporation, Analysis for Military Decisions, by E.S. Quade (ed.). RAND publication R-387-PR (Santa Monica, Calif.: The RAND Corporation, November, 1964), 3. On page four Quade defines systems analysis as follows: "When used in a military context, the label 'systems analysis' is applied very broadly to any systematic approach to the comparison of alternatives."

desired might be measured by the ability to destroy a large number of enemy targets after sustaining a nuclear first strike. The weapons system itself includes not only the required number of missiles and their submarine launching platforms, but the trained crews, supply ships, and maintenance, overhaul, and operating bases needed for their support.

The discounting procedure discussed in this paper applies primarily to procurement and force composition systems analyses; that is, studies to decide what systems to buy or develop now so that future military forces will have the desired capabilities. This type of analysis is undertaken to assist a decisionmaker, who, being faced with a general future requirement, must decide whether to develop, buy and operate one system or a combination of two or more systems now. If a combination of two or more systems is viewed as itself comprising a system, then the decisionmaker's job can always be described as choosing a single system from among the alternatives.

Defense Department systems analyses have generally evolved as economic analyses, or "cost-effectiveness" studies.<sup>3</sup> Cost-effectiveness studies are so named simply because the two main system features studied are the system cost and the system effectiveness.

System effectiveness has been a traditional concern of the military services, and the specific investigation

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<sup>3</sup> Enthoven, op. cit.

of effectiveness in studies of future weapons systems is not new. The effectiveness of a system is defined as the degree to which the system is able to accomplish a stated objective. Although system effectiveness is easily defined, its correct measurement is one of the most difficult problems systems analysts face. First there is the deceptively difficult problem of choosing the correct unit of measurement.<sup>4</sup> Of equal difficulty is the problem of applying this measure to a future situation which is pervaded by uncertainties.<sup>5</sup>

The cost of a system is defined to be the sum of the real costs of the resources used by that system during a given time period. Resource costs are measured by their opportunity cost. That is, the cost of a resource in some specific use is the value of that resource in its best alternative use.<sup>6</sup> Since the procurement and force composition cost-effectiveness studies which are being considered in this paper involve consideration of future time periods, in which the supply of a given resource is not rigidly fixed, it is perhaps safe to assume that resource costs can be measured in dollars.<sup>7</sup> It is because the total

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<sup>4</sup> Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age (Cambridge: Harvard University Press, 1963), 179-181.

<sup>5</sup> Ibid., 188-192.

<sup>6</sup> Ibid., 26.

<sup>7</sup> Ibid., 24-28.

supply of resources available to the Department of Defense is limited that system costs become such an important consideration in military cost-effectiveness studies.<sup>8</sup>

Assume that the decisionmaker has been provided with the cost and effectiveness of each of several alternative systems proposed to accomplish an objective. The decisionmaker must choose the "best" of these systems, but what criterion does he use to identify that system?<sup>9</sup> He could choose the most effective system without regard to cost, but if systems were designed to meet this criterion their costs would undoubtedly be prohibitively high. Carried to the extreme, the use of this criterion could result in spending all available resources on a system which is extremely effective in some single mission, and thus being unable to accomplish all other objectives. Alternatively, the decisionmaker could choose the least-cost system. But designing a system to minimize costs alone would ultimately lead to a zero cost, zero effectiveness system. The least cost criterion which could lead to choosing such a system is clearly a bad one. A criterion of choosing the system for which the ratio of system cost to system effectiveness is lowest, without regard to the actual magnitudes of cost

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<sup>8</sup> Ibid., 23.

<sup>9</sup> The next two paragraphs briefly outline the selection of a proper decision criterion. For a more comprehensive treatment of this problem, see Hitch and McKeon, Ibid., 164-168.

or effectiveness, could result in equally undesirable choices. Similarly if cost is measured in dollars and effectiveness is measured in some other unit, as is usually the case in military analyses, then the criterion of choosing that system for which the difference between effectiveness and cost is a maximum is infeasible, since that difference is undefined.

Either of two conceptually equivalent criteria appears best. Systems can be designed so that the costs of each system over the relevant time period are equal. If this is done, the correct criterion is to choose the most effective of the systems. The problem in this case is determining what the fixed cost level should be, since future defense budgets are not fixed. Alternatively and equivalently, systems can be designed so as to have equal effectiveness over the relevant time period. In this case, the correct criterion is to choose the least-cost system. Again the problem is to determine what the fixed effectiveness level should be, but this is often at least roughly indicated by the objective to be met. Although the discounting procedure discussed in this paper is applicable to studies using either of these equivalent criteria, the development of discounting in this paper will be based on systems studies which are designed to hold the effectiveness levels of the alternative systems equal.

An understanding of the general methodology of cost-

effectiveness studies<sup>10</sup> is also important for determining the proper discount rate. The decisionmaker first provides a general scenario for the study. This scenario includes the time frame for the study, the general enemy threat posed, and a general description of friendly forces. It may or may not include more specific guidance regarding budget levels, enemy capabilities, allies, strategic constraints, etc. A project leader is appointed to direct the study and to coordinate the efforts of the members of the study team. Within the study team one group of analysts proposes the alternative weapons systems, devises a measure of effectiveness, decides the level or levels at which effectiveness will be fixed, and through operations analysis techniques determines the configuration and number of units required over time to achieve the desired effectiveness. A second group of analysts estimates the costs of the proposed systems, using the system configurations and number of units required as inputs.

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<sup>10</sup>As summarized from a lecture by Mr. Patrick J. Parker, Center for Naval Analyses, Naval Warfare Analysis Group, Arlington, Va., to the Operations Analysis curriculum students of the U. S. Naval Postgraduate School, Monterey, Calif., November 19, 1964.

### 3. The Discounting Process.

In the last section the decision problem in cost-effectiveness studies was limited to the case where two or more equally effective alternative means of achieving some objective have been identified. The criterion for choice between these systems is that of least cost. But what cost figures should be compared in the decision-making process? The question arises because the costs of the alternative systems are estimated over a future time period, a period which usually is several years long and which often extends over the expected useful lifetime of one or more of the systems.

It is possible that the sum of the research and development, initial investment, and operating costs of one of the alternative systems will be strictly less than the corresponding costs of each of the other systems in every year of the time period under consideration. In this case one system is clearly the least cost system, and no further comparison of costs would be necessary. However, it is often the case that one system will have higher costs than another system in one or more years of the time period under consideration, but that the reverse will be true for the remaining years. A typical example is where one system is an existing system requiring no research, development, or initial procurement, but which will incur increasingly heavy operating and replacement costs in the future. The other system is a new

system requiring relatively heavy research, development and initial investment costs, but whose operating and replacement costs will be relatively low once that system becomes operational. In this more usual case the least-cost criterion will fail to identify a preferred system, unless the term "cost" is modified to include a specification of how costs occurring in different time periods are to be weighted.

The decisionmaker could give costs in all time periods equal weight and compare the total costs of each system. However, costs incurred in different time periods are not equivalent, even assuming constant prices for all resources. This is easily appreciated by considering a situation on the level of personal finances. If a person could receive an expensive item today, would he rather pay for it today or a year from now? Payment a year from now is clearly preferable, since just by leaving the amount of money involved in a savings account for a year he could make the payment then and still retain the interest earned on the account. Of course there are other ways to make money "work" over time. Regardless of the reason for the time preference, however, the mere existence of a preference between present and future expenditures is sufficient to show the non-equivalence of costs occurring at different times.

It would seem that the decisionmaker should assign

different weights to costs occurring in different time periods, and then compare the system weighted-cost totals. This is a better procedure, but what weights should be assigned to costs occurring in different time periods, and how should the total time period under consideration be subdivided for purposes of cost measurement?

One way of assigning different weights to costs occurring in different time periods is the discounting procedure. This procedure assumes that a discount rate exists in each time period, not necessarily the same rate for each time period. The discount rate is most easily explained by considering it as an interest rate. If an amount of money,  $V_0$ , is invested today in a use offering a 4% return per time period, then the value,  $V_1$ , of the investment at the end of one time period is

$$\begin{aligned} V_1 &= V_0 + .04V_0 \\ &= (1 + .04)V_0 \\ &= 1.04V_0 \end{aligned}$$

Equivalently, the amount of money,  $V_0$ , which invested at 4% per time period will yield a return of  $V_1$  is

$$\begin{aligned} V_0 &= \frac{V_1}{1.04} \\ &= \frac{V_1}{1 + .04} \end{aligned}$$

If the amount is invested for two time periods at the same rate, then its value,  $V_2$ , at the end of two time periods is given by

$$\begin{aligned}
V_2 &= V_1 + 1.04V_1 \\
&= (1 + .04)V_1 \\
&= (1 + .04) [(1 + .04)V_0] \\
&= (1.04)^2 V_0 .
\end{aligned}$$

Again solving for  $V_0$ ,

$$\begin{aligned}
V_0 &= \frac{V_2}{(1.04)^2} \\
&= \frac{V_2}{(1 + .04)(1 + .04)} .
\end{aligned}$$

In general, let

$t$  = number of time periods

$i_j$  = interest rate in the  $j^{\text{th}}$  time period;  $j = 1, \dots, t$

$V_j$  = value of the investment at the end of  $j$  time periods

Then,

$$V_t = (1 + i_t)(1 + i_{t-1}) \dots (1 + i_1)V_0 ,$$

or

$$V_0 = \frac{V_t}{(1 + i_1)(1 + i_2) \dots (1 + i_t)} .$$

If  $i_j = i$  for all  $j = 1, \dots, t$ , then

$$V_0 = \frac{V_t}{(1 + i)^t} .$$

If one is interested in computing  $V_t$ , given  $V_0$  and  $i_j$ ,  $j = 1, \dots, t$ , then the  $i_j$  are called interest rates. If it is desired to compute  $V_0$ , given  $V_t$  and the  $i_j$ , then the  $i_j$  are called discount rates.

The same discounting procedures can be applied to costs.

If our time preference is such that we consider the payment of a cost of  $C_0$  now as equivalent to the payment of an increased amount,  $C_1 = C_0 + iC_0$ , one time period from now, then to obtain the present value of that future cost,  $C_1$  must be discounted by  $1+i$ ; that is,

$$C_0 = \frac{C_1}{(1+i)^1} .$$

Similarly, assuming that our time preference remains constant from year to year, the present value of a cost which will be incurred  $t$  time periods from now is

$$C_0 = \frac{C_t}{(1+i)^t} .$$

The present value of the sum of the costs which will be incurred in each of  $t$  future time periods is given by

$$C_0 = \sum_{j=1}^t \frac{C_j}{(1+i)^j} .$$

Note that the weighting factor applied to costs in different time periods here is  $(1+i)^j$ , and not the discount rate,  $i$ , itself.

Theoretically, the non-equivalence of costs in different time periods leads to continuously varying the weighting factor applied to costs over time. That is, the total time period under consideration should be divided into infinitesimal increments. However, if the length of the total time period is several years, as it is in studies of weapons systems over their expected useful lives, then the choice of yearly time increments should provide a number of time

periods over which to discount costs adequate to reflect the influence of time preferences. The breakdown of the total time period under consideration into yearly increments is convenient for Defense Department cost-effectiveness studies, since historical cost data are generally maintained in the government by fiscal year. Also, the choice of the fiscal year as the basic time period is compatible both with Congressional allocation of money to the various governmental departments and with the Department of Defense programming system.<sup>1</sup>

It is generally considered that two factors combine to determine the discount (interest) rate.<sup>2</sup> The first of these is the factor already considered; that is, the time preference of the investor. If the discount rate accounted for only this factor, then for a given time preference the degree to which a future cost or benefit would be discounted to obtain its present value would depend only upon the remoteness of that cost or benefit. However, the discount (interest) rate should also reflect the degree of risk involved. Thus the interest rate on loans is higher the more likely it becomes that the cost will never be incurred.

The discount rate will hereinafter be thought of as

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<sup>1</sup>Office of the Assistant Secretary of Defense (Comptroller) Programming, Directorate for Systems Planning, Study Report on the Programming System for the Office of the Secretary of Defense. Washington: June 25, 1962.

<sup>2</sup>J.R. Hicks, Value and Capital. (Oxford: Oxford University Press, 1946), 142-143.

being the sum of these two factors. That is

$$i_j = i_{jN} + i_{jR} ; j = 1, \dots, t ,$$

where  $i_{jN}$  is the normative factor of the discount rate in time period  $j$ , and  $i_{jR}$  is the risk premium factor of that discount rate. In the case of Defense Department force composition cost-effectiveness studies, it seems reasonable to assume that neither would the Defense Department's time preference vary in any predictable manner over future years, nor would the degree of riskiness of a given defense system cost vary from year to year, except as a function of its remoteness from the present. Making these assumptions; i.e., that

$$\left. \begin{array}{l} i_{jN} = i_N \\ i_{jR} = i_R \end{array} \right\} \text{ for all } j = 1, \dots, t.$$

the equation for the present value of the sum of the costs expected to occur in each of  $t$  future years becomes

$$C_0 = \sum_{j=1}^t \frac{C_j}{(1 + i_N + i_R)^j} .$$

The solution to the problem of what weights to assign costs occurring in different time periods for these Defense Department cost-effectiveness studies now depends upon finding what values to assign to  $i_N$  and  $i_R$ .

#### 4. The Normative Component.

This section considers the component of the discount rate that reflects only the time preference of the Department of Defense, which is independent of the riskiness of the investment projects being considered. That is, we seek the normative component,  $i_M$ , which when added to the risk component,  $i_R$ , comprises the proper discount rate for military cost-effectiveness studies.

At first we continue to consider the discount rate as an interest rate. One suggestion for determining which interest rate applies to government projects is to use the rate at which the government can borrow funds.<sup>1</sup> The idea here is that the government raises marginal funds by borrowing, and hence the government borrowing rate is a measure of the government's time preference. Since the Department of Defense cannot borrow by itself, but rather must have the government borrow for it, the rate at which the government borrows would seem to be applicable to the Department of Defense. Since the defense investments under consideration are typically long term projects, the most suitable government borrowing to consider would be the interest rate on long term government bonds. This rate has the further advantage of being as risk-free a rate as can be found.

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<sup>1</sup> Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age (New York: Harvard University Press, 1963), 210.

Using this rate, say  $r_B$ , the argument for discounting future costs is analogous to the example of the private lender presented in the last section. If the government borrows and spends an amount  $C_0$  today, it would have to repay  $C_1 = (1 + r_B) C_0$  one year from now.

The critical assumption leading to the use of this rate is that the government must finance marginal investments by borrowing. It is an invalid assumption for several reasons. The defense investment projects under consideration are assumed to be long term projects; i.e., they incur costs over a period of several years. Neither the Defense Department budget nor the federal budget can be considered as fixed over such a time period. Hence if the costs are programmed in advance they can be financed through taxation, with tax rates being adjusted as required. Even in the short term, fixed budget case, the government is not limited to borrowing as a means of raising funds. For instance, the government can create new money and adjust future monetary and fiscal policies as necessary to compensate for its impact on the economy. The rate at which the government can borrow funds must be rejected as a measure of  $i_M$ , then, on the grounds that although it is a conveniently measured risk-free rate, it is simply not relevant to the situation being considered.

One writer has suggested that the rate at which the marginal utility of a good decreases per unit increase in

the available quantity of the good should be the basis for discounting future values.<sup>2</sup> The national product is thought of as the "good" involved. The argument is stated as follows.

"Since the national product will increase from year to year in a well-run economy, the resources diverted to investment from this year's income should be weighted more heavily than the resources paid back next year by that investment. Thus the present cost of an investment should be weighted more heavily than its future savings, not because the savings are deferred in time, but because the savings are part of a larger national product per capita than was the initial cost, and hence represent a lower marginal utility."<sup>3</sup>

It would appear that the same reasoning could be applied to discounting future costs as is suggested above for discounting future savings, or returns.

There is little doubt that the Defense Department would place a higher marginal utility on each dollar if it were constrained to operate within a relatively low yearly budget. Presumably both the amount of defense output (effectiveness) required, as determined by the degree of enemy threat, and the amount of inputs required to produce that output, as determined by the state of technology, would remain constant within a given year, so that the availability and use of additional inputs would produce diminishing returns. Hence the marginal utility of the inputs, dollars in

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<sup>2</sup>E. B. Berman, "The Normative Interest Rate", RAND publication P-1796 (Sept. 15, 1959), 22.

<sup>3</sup>Ibid.

this case, would decrease as their supply increased.

The introduction of the time dimension, however, may render the marginal utility concept inapplicable. Consider a Defense Department objective of being able to destroy a certain number of enemy targets. Assume that the forces have been organized ("produced") in such a way as to accomplish that objective this year, at a certain cost,  $C_0$ , paid out of this year's budget. Assume that the growth of national product results in an increase in the Defense Department budget next year. Assume also that the defense objective remains unchanged from this year to next year, but that the enemy develops a better defensive capability against our existing forces. Suppose that the nature of our forces and the technological means of producing them remains unchanged, so that more units must be produced in order to meet the objective. In this case the money available to purchase inputs is increased, but so is the number of units required. The marginal utility of money, which is a measure of the satisfaction derived from the marginal dollar, may next year be greater than, equal to, or less than the marginal utility of money this year, depending upon the relation between the percent increase in the defense budget and the percent increase in the input requirements. Diminishing marginal returns remain characteristic of the production process, but their effect may be offset by the increased utility of the marginal unit, in the relevant range.

An easily understood analogy is provided by people and their incomes. As a person's income rises (until very high incomes are reached) he becomes accustomed to more expensive and varied goods, and he incurs more expensive recurring obligations. If the person's job is such that increasing social demands are placed on him as his income increases, it sometimes happens that his expenditure "requirements" (those expenditures which he feels are necessary) increase faster than his income. In such a situation it is likely that at the lower income his satisfaction is at a certain level, whereas at the higher income his satisfaction is relatively lower, because of his changing tastes and obligations. The marginal utility of money to him is higher in the latter case, even though the amount of money he controls has increased. In terms of indifference curve analysis, his utility isoquants have moved away from the origin faster over time than has his opportunity line (assuming an opportunity line of constant slope and unchanged shapes of the utility isoquants).<sup>4,5</sup>

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<sup>4</sup>For a basic explanation of indifference curve analysis for individual income allocation and resource allocation by a firm, see Richard H. Lipton, The Price System and Resource Allocation (New York: Holt, Rinehart and Winston, 1960), 69-79 and 126-135.

<sup>5</sup>For an application of indifference curve analysis to capital budgeting, see Jack Hirshleifer, "an Isoquant Approach to Investment Decision Problems", RAND publication P-1158 (August 23, 1957).

The rate of growth of national product, and of the Department of Defense budget, is therefore rejected because the diminishing marginal utility assumption does not necessarily apply to the Defense Department when costs are to be incurred over time.

A third suggestion is that the proper discount rate to be used is the rate of return on the marginal private investment.<sup>6</sup> When national investment resources are optimally allocated the rates of return on marginal investments should be the same in both the public and private sectors. The return referred to is the return to capital (i.e., production equipment, inventories, education, research) made possible by the marginal productivity of capital.

The rate of return on a defense investment is usually impossible to measure directly, since the costs and returns of such an investment are incommensurable. Investment costs are usually measured in dollars, whereas the returns are in such units as ability to destroy enemy targets, or more generally, "military effectiveness units". Congress allocates investment funds to the various governmental departments through its control of the yearly budget. Presumably Congress attempts to do so in such a way that the marginal returns on investments in each of the departments is equalized. Therefore, an appropriate measure of the marginal rate of

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<sup>6</sup>Berman, *op. cit.*, 5.

return to Defense Department investments should be the marginal rate of return on investments of other governmental departments.

The same measurement problem exists in other governmental departments, however, as in the Department of Defense. Except for a few relatively small scale operations, the returns on government investments are not measurable in dollars.<sup>7</sup> What is the dollar value, for instance, of the intergovernmental communications channels maintained by Foreign Service Officers of the State Department? The return on governmental investments usually contains a substantial non-monetary direct return to the welfare of the country.<sup>8</sup>

Congress not only allocates funds within the government, but in deciding on the magnitude of the budget, Congress presumably allocates funds to the government in such a way that the marginal return on governmental investments is equated to the marginal return on investments in the private sector. Since governmental returns and private returns are generally incommensurable, it is granted that Congress' allocation decisions are made on a subjective rather than a

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<sup>7</sup> For the results of an attempt to measure the dollar output of certain activities of the Department of the Interior, see RAND Corporation, A Case Study in the Measurement of Government Output, by W. A. Vogely. RAND Corporation publication RM-1934-RC (Santa Monica, Calif.: The RAND Corporation, July 9, 1957).

<sup>8</sup> Berman, op. cit., 2-4.

strictly quantitative basis. Nevertheless, these allocations are made, and presumably the intent of Congress is to make them optimally.

If it is assumed that Congress is able to, and does, allocate the national income so as to equalize the marginal rates of return in the public and private sectors, for given yearly national incomes, then the rate of return on the marginal governmental investment, and in particular the rate of return on the marginal investment within the Department of Defense, can be quantified by measuring the rate of return on the marginal private investment at given yearly incomes. If it is further assumed that long run competitive equilibrium exists in the private sector, so that for a given national product and degree of risk each investment opportunity will yield the same rate of return (i.e., all firms are operating at the margin), then an average over degrees of risk of the rates of return to investment in the private sector would provide a measure for the rate of return to marginal Defense Department investments having that same (private industry average) degree of risk. The rate so determined would not serve as the risk-free normative rate originally sought, but it could nevertheless serve as  $i_M$  if the risk factor were redefined to encompass only the additional risk of the investment under consideration.

Berman maintains that the marginal rate of return to investment in the private sector is not a clearly defined

measure, because it varies with the level of total investment considered.<sup>9</sup> It is true that the marginal rate of return is inversely related to the total investment level, if the generally accepted assumption of diminishing marginal returns to capital is made.<sup>10</sup> Berman's argument is that since the government can control the total level of investment by fiscal and monetary policies aimed at controlling the growth rate of national product, the government should not use the marginal rate of return in the private sector as a fixed constraint on its investment planning.

In the context of this paper, that of the Department of Defense making investment decisions between alternatives available within that department, however, the Department of Defense must consider the investment level in the private sector as a factor independent of its operations. The President recommends fiscal policies leading to a desired growth rate of national product. These policies are modified and approved by Congress. The desired growth rate determines the level of total investment for the economy. Through its control of the federal budget Congress essentially allocates investment funds between the private and public sectors of the economy, and presumably does so in such a manner that

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<sup>9</sup> *Ibid.*, 7.

<sup>10</sup> George J. Stigler, The Theory of Price (revised edition: New York: The MacMillan Company, 1952), 111.

the rates of return in the private and public sectors are equalized. Hence for a governmental policy promoting any rate of national growth,<sup>11</sup> a policy which the Department of Defense neither recommends nor determines, the Department of Defense can consider the rate of return in the private sector of the economy as an independent measure of the rate of return to its own investment activities.

To make actual measurements on the rate of return to average risk private investments, values of national product and the desired growth rate, and hence the level of investment, must be specified. Historical information will not tell us what the rate of return would have been had the investment level been different, so measurements must be made on actual past rates of returns to investments.

If the desired growth rate, and hence future national products and investment levels, are not known, then perhaps the best approximation is to assume that historical national products and investment levels determined by governmental monetary and fiscal policies reflect the desired growth rate. Then if it is assumed again that private firms are operating at the margin, the marginal rate of return on investment in the private sector, averaged over the degrees

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<sup>11</sup>For a treatment of how governmental policies affect the interest rate, see H. Liebenstein, "Economic Development and the Rate of Interest Under Dictatorial Conditions", RAND publication P-808 (Feb. 28, 1956).

of risk involved, could be obtained by computing the yearly rate of return at each risk level, averaged over a number of recent years, and then weighting these rates according to the proportion of total investment funds which were used at the various risk levels in order to get an over-all average. This is essentially the approach taken by one private research corporation under Navy contract to determine what interest rate should be used in evaluating the holding cost of military inventory.<sup>12</sup> The average rate of return on real capital investment in the American economy was measured to be 16.5%.<sup>13</sup>

The marginal rate of return on investment in the private sector of the economy is accepted as the appropriate measure of the redefined normative component of the discount rate which the Department of Defense should use in procurement and force structure cost-effectiveness studies. The redefined normative component is the component of the discount rate which measures the Defense Department's time preference in investment decisions involving a degree of risk equal to that of the average investment in the private sector.

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<sup>12</sup>Planning Research Corporation, The Interest Cost of Holding Military Inventory, by J. A. Stockfish. P. R. C. report number PRC R-156 (Los Angeles, Calif.: Planning Research Corporation, May 5, 1960).

<sup>13</sup>Ibid., 14.

## 5. The Risk Component.

The risk premium component of the discount rate originally was defined as the factor by which the normative component of the discount rate must be modified to reflect the riskiness of the investment; i.e., the likelihood that the returns or costs will never be incurred. Since the marginal rate of return to average risk investments in the private sector has been chosen as the measure of  $i_N$ , it is clear that  $i_R$  must be redefined. The normative component as chosen already includes an average allowance for risk. We redefine the risk premium component,  $i_R$ , to be the factor by which the normative component,  $i_N$ , must be modified to reflect the difference in degree of risk between the type of investment being considered to meet the defense objective and the average investment in the private sector.

In order to assess the riskiness of an investment we must determine exactly what is meant by risk. There are three major reasons why military investments are risky.<sup>1</sup> First, the actual effectiveness of a system being invested in may be less than anticipated, and in fact may never be realized at all. Secondly, a system may actually cost more or less than is estimated at the time of the investment

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<sup>1</sup>Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age (Cambridge: Harvard University Press, 1963), 210.

decision. Thirdly, anticipated future costs may never be incurred.

The uncertainty as to the degree of effectiveness which will be achieved by the system stems from several sources. Perhaps the system cannot be developed as planned because a technological barrier is encountered. In this case the system probably would be developed, but at a lesser effectiveness than planned. The performance characteristics might have to be changed; lower speed, less payload, etc. The system's survivability, or ability to survive an enemy offensive attack, might be diminished. The reliability of the system might be lowered, resulting in mission aborts and hence less offensive units on target. Or the ability of the weapon system to overcome enemy defenses at the target might be diminished, again resulting in less targets destroyed.

The structure and methodology of the cost-effectiveness studies under consideration indicate that the degree of uncertainty in future effectiveness should not be reflected in the risk component of the discount rate. This uncertainty is more properly treated in these studies by the effectiveness analysts than by the cost analysts. Having set a desired level of effectiveness, it is the effectiveness analysts' job to compute the required number and type of units for which the cost analysts are to estimate system costs. If the effectiveness analysts are uncertain of the number and

type of units which will be required to attain the desired level of effectiveness because of technological uncertainty, then these analysts should run a sensitivity analysis. Such an analysis would yield several different combinations of type and number of units required, as a function of input assumptions made on the technological feasibility of producing the desired system. Each of these combinations could then be costed separately by the cost analysts.

Next consider the uncertainty of the cost estimates made for a specific system. Cost estimates are uncertain for a number of reasons.<sup>2</sup> Prices may be different at the time costs are to be incurred than expected. It may be possible to make general price level adjustments to system costs, but the actual prices which will apply cannot be predicted with certainty. Different cost analysts working on the same study may use somewhat different methods, or may differ in their competence. Hence the costs estimated may depend upon who estimated them. The cost estimating relationships, such as linear estimating equations<sup>3</sup> and learning curve calcula-

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<sup>2</sup>RAND Corporation, A Discussion of Uncertainty in Cost Analysis, by G. H. Fisher. RAND publication RM-3071-PR (Santa Monica, Calif.: The RAND Corporation, April, 1962), 12-19.

<sup>3</sup>For a discussion of the use of statistical regression analysis in deriving estimating relationships, see RAND Corporation, Derivation of Estimating Relationships: An Illustrative Example, by G. H. Fisher. RAND publication RM-3366-PR (Santa Monica, Calif.: The RAND Corporation, Nov., 1962.

tions,<sup>4</sup> may be in error, resulting in erroneous cost estimates. Even if the cost estimating relationships are correct, the historical cost data on which future costs are based may be inaccurate. Finally, even if the data and cost estimating relationships are correct it is often necessary to extrapolate beyond the range of the past data in making estimates of future costs.

It is tempting to account for cost estimating uncertainty in the risk component of the discount rate, and such a procedure has been proposed [5]. The less certain an investor is of how much it will cost to obtain a given return, the less likely he is to make the investment. Notice, however, that the more future costs are discounted (i.e., the higher the discount rate), the more likely that investment is to be chosen in comparison with alternative investments which provide the same total return. To decrease the chance that an investment having highly uncertain costs would be chosen, it would be necessary to decrease the risk component of the discount rate. This would imply setting  $i_R$  at some arbitrary rate for investments with no cost estimating uncertainty, and then decreasing that rate in proportion to the variability of the costs of investments having cost estimating uncertainty. But the variance of the cost estimate

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<sup>4</sup>For a discussion of cost-quantity calculations, see RAND Corporation, Cost-Quantity Calculator, by J. W. Noah and R. W. Smith. RAND publication RM-2786-PR (Santa Monica, Calif.: The RAND Corporation, Jan., 1962).

extends the possible costs to values both above and below the estimated cost, conceivably ranging from zero to infinite cost.

Consider the actual cost in time period  $t$  as a random variable,  $C_t$ , having a subjectively assigned probability density function,  $f_{C_t}(c_t)$ , characterized by the estimated cost as its mode and by some unknown mean and variance.

That is,

$C_t$  = actual cost in time period  $t$ , a random variable distributed as  $f_{C_t}(c_t)$  for  $0 \leq c_t < \infty$

Mode  $[C_t] = \hat{c}_t$ , the estimated cost

$E [C_t] = \mu_{C_t}$

$\text{Var} [C_t] = \sigma_{C_t}^2$

Then the probability density function of  $C_t$  might have a graph like the following:

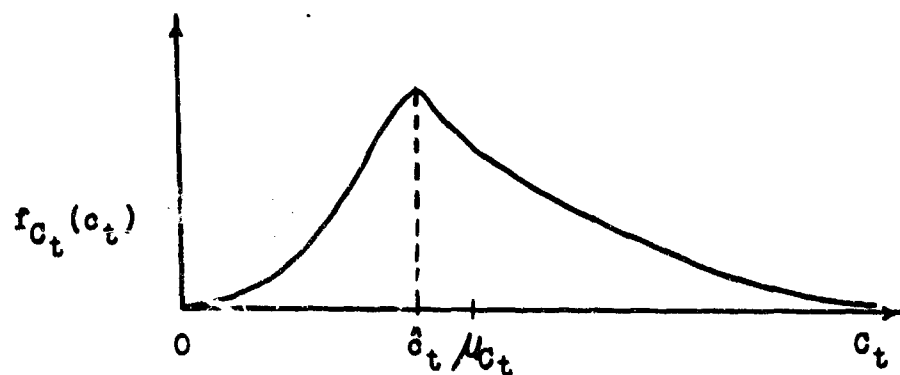


Figure 1.

Such a graph would reflect the analyst's evaluation of  $\hat{c}_t$  as the single most likely value of  $C_t$ , and would also reflect his knowledge that more historical estimates have proved to be too low than too high.

Assume that  $i_R$  is assigned a value of zero for a com-

pletely certain cost estimate. Then if  $i_R$  is reduced to account for some amount of uncertainty (variance) in  $\hat{c}_t$ , it is clear that the present value of  $\hat{c}_t$  can only become larger.

Let  $\hat{c}_0 =$  present value of  $\hat{c}_t$  when  $i_R = 0$

$\hat{c}'_0 =$  present value of  $\hat{c}_t$  when  $i_R = -k$ ,  $0 < k < 1 + i_N$ .

Then

$$\hat{c}_0 = \frac{\hat{c}_t}{(1 + i_N)^t}$$

and

$$\hat{c}'_0 = \frac{\hat{c}_t}{(1 + i_N - k)^t}$$

so that

$$\frac{\hat{c}'_0}{\hat{c}_0} = \frac{(1 + i_N)^t}{(1 + i_N - k)^t}$$

Then

$$(1 + i_N)^t > (1 + i_N - k)^t$$

implies that

$$\hat{c}'_0 > \hat{c}_0$$

or

$$\hat{c}'_0 = \hat{c}_0 + K, K \text{ a positive valued function of } k.$$

If the actual value of  $C_t$  turns out to be greater than  $\hat{c}_t$ , then we would want its present value to be greater than  $\hat{c}_0$ , and the reduction of the discount rate would produce that effect. On the other hand, if the realized value of  $C_t$  is less than  $\hat{c}_t$ , then we would want its present value to be less than  $\hat{c}_0$ . This result cannot be produced by reducing

the discount rate, as shown above. And yet by assigning the estimated cost,  $\hat{C}_t$ , as the mode of a subjective probability distribution of  $C_t$ , the cost analyst has admitted that  $C_t$  may take on a value less than  $\hat{C}_t$ . The analyst cannot both decrease the discount rate to account for costs higher than those estimated and increase the discount rate to account for costs lower than those estimated at the same time. Another method for accounting for cost variability must be found.

Perhaps the best method available for this purpose is sensitivity analysis.<sup>5</sup> That is, for each specific system being analyzed, the cost analyst should assign several different sets of prices as inputs, and then present the resulting best cost estimates as his output. The decision-maker can obtain a feeling for the degree of uncertainty in the cost estimates from these results.

Finally, consider the possibility that future costs may never be incurred. The threat posed by the enemy may change, so that the systems being studied may be discontinued at some time within the time period of the study. This is analogous to changes in customer taste in commercial investment planning, but is perhaps even more likely to occur than in private industry in today's rapidly changing world.

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<sup>5</sup>For an alternative method based on an expectation-variance principle which establishes the risk component at some specified level of confidence, see J. M. English and R. H. Hasse, "Economic Selection of Alternative Risk Investments." RAND publication P-2869 (Feb., 1964).

Or perhaps the military systems being considered will become technologically obsolete within the time period of the study, and hence will be replaced by a new system as a result of future procurement or force structure cost-effectiveness studies. The rapid turnover in combat aircraft provides an historical example of this phenomenon. The possibility also exists that a previously approved program of one of the services could be prematurely terminated because of an administrative failure by that service to present proper and convincing program data within the framework of the Department of Defense programming system. Or economic conditions might deteriorate in the future, so that it would be economically undesirable to continue an approved system because of total budget limitations.

It is important to distinguish the difference between the uncertainty about costs caused by the variability of cost estimates and that caused by the possible situation in which the costs are accurately estimated, but never are incurred. The former uncertainty should be accounted for by a cost sensitivity analysis. The degree to which the system costs might never be incurred is the part of investment risk which should be reflected by the risk component of the discount rate. Actually, having chosen the marginal rate of return to average-risk investments in the private sector as the measure of  $i_m$ , it is the greater or lesser likelihood that future system costs will not be incurred, as compared

to the average-risk private industry investment, that should determine  $i_R$ . Because of the changing threat posed by the enemy and the high rate of technological obsolescence which affect military systems, it is reasonable to assume that for most types of systems considered the risk component of the discount rate would be positive, and, for many of these cases, quite large.

To illustrate why the likelihood of non-occurrence of future costs should be included in the discount rate, consider the following situation. The defense objective is to have the ability to destroy a certain number of enemy targets after sustaining an offensive strike by the enemy. Two systems are designed so that the system characteristics and number of units contemplated are such that an equal level of effectiveness is expected to be achieved by both systems in each of the next  $T$  years. The sum of research and development, initial investment, and operating costs are estimated for each system in each of the  $T$  years. A plot of costs versus time for the two systems is as follows:

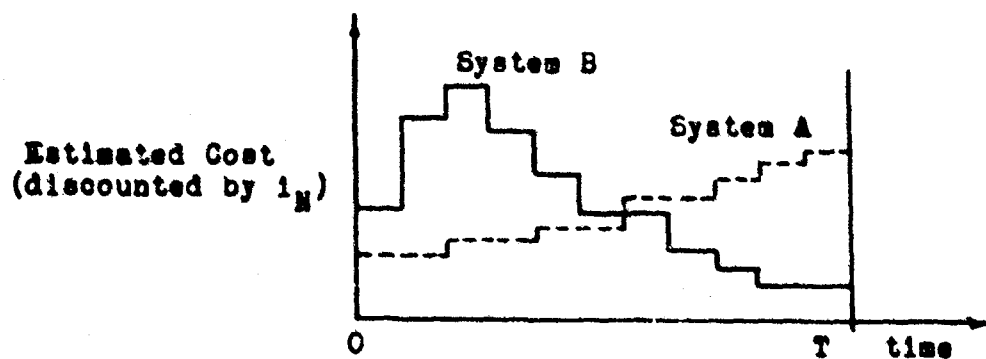


Figure 2.

Assume that the present values of the total costs; that is, the total costs discounted by  $i_N$ , for systems A and B are very nearly equal. System A is a bomber force of which several units are operational at year zero. Operating costs for this system will increase as the bombers wear out, and perhaps new units of these bombers will have to be procured before year T. System B is an as yet undeveloped land based missile system. Initially the development and procurement costs will be high for this system, but once operational the operating costs will be low. Assume further that at year zero it is considered fairly likely that one or both of two things might happen sometime before year T: (1) a disarmament agreement will be made with the enemy, and/or (2) system C, a superior submarine-based missile system, will become available which would replace either system A or system B. Since we feel that some of the later costs of both system A and system B may not be incurred, we should prefer to choose now the system whose earlier costs are the lower, in this case system A. Introducing an additional positive risk component,  $i_R$ , into the discounting procedure would lead to system A having a lower present value of total cost than system B, and hence for equal effectiveness, system A being the preferred system.

To summarize, the risk component,  $i_R$ , of the discount rate is a measure of the degree to which it is likely that estimated future costs will never be incurred, as compared

with average investment conditions in the private sector of the economy. The degree to which it is likely that future costs will not be incurred depends upon the type of systems being considered, and not on the characteristics of the individual systems themselves. Since the magnitude of this element of cost uncertainty depends upon a subjective probability, the  $i_R$  component of the discount rate should be assigned subjectively by the study group.

## 6. Presentation of Results.

After the effectiveness and cost calculations and the sensitivity tests on each have been made by the analysts of a cost-effectiveness study, the results obtained must be presented to the decisionmaker in a form which will enable him to apply his decision criteria in choosing between the systems studied. The criterion considered in this paper is least cost for a given level of effectiveness.

Assuming this decision criterion, the decisionmaker must be told at what level effectiveness has been fixed in the study. A rationale for choosing the measure of effectiveness used in the study should be given. Also, an effectiveness sensitivity analysis should be presented to show the effect that different input assumptions would have on system characteristics and the number of units required. Since sensitivity tests of a complex system must be limited to consideration of a relatively small number of "interesting" parameter combinations, the decisionmaker can get a good feeling for the effectiveness risk of the systems if he is provided with the analysts' rationale of why the chosen parameter combinations were "interesting".

The next data the decisionmaker needs are the system costs. Costs should be presented in each of three different forms. First the undiscounted estimated yearly costs should be presented for each system. This time stream of cost occurrence may indicate to the decisionmaker that one or more

systems simply cost too much in a given year, and are therefore infeasible. If, for instance, the Five Year Force Structure and Financial Plan has already programmed a high peak of costs in some particular year, then it would be desirable to avoid heavy additional costs in that year in order to maintain a degree of balance in the total defense budget over time.

Secondly, the present value of the total cost of each system, discounted by  $i_N$  only, should be presented. The normative component of the discount rate applies to all Department of Defense investment programs, regardless of the type of systems being considered. Presentation of this discounted cost provides a single cost figure for each system, one which is more meaningful than would be an undiscounted total system cost figure.

Finally, the present value of the total cost of each system, discounted by the sum of  $i_R$  and  $i_N$ , should be presented. Insofar as the analysts have subjectively assigned the proper value to the risk component, this completely discounted total cost figure will be a more meaningful measure of total system cost than the total cost discounted by the normative component alone. Since the value of this figure depends upon what subjective value of  $i_R$  was assigned by the analysts, the rationale for assigning that value should be presented to the decisionmaker, as well as the sensitivity of fully discounted total system costs to higher and lower

values of  $i_R$ .

All three of these cost figures, the time stream of undiscounted costs, the partially discounted total system cost, and the fully discounted total system cost, should be presented not only for the single best estimate of the system characteristics and number of units required, but also for each of the variations resulting from the effectiveness sensitivity analysis. In addition, the sensitivity of these cost figures to cost variability should be presented so that the decisionmaker can get a feeling for the degree of uncertainty in the cost estimates.

If the various sensitivity analyses result in one system being preferred under certain conditions and another system being preferred under others, then the decisionmaker must make his selection between systems subjectively. However, the quantitative data available and the rationales presented in the study should aid the decisionmaker considerably in making his decision.

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