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Allocating HIV Prevention Resources

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Abstract—This year, the federal government will spend upwards of $600 million on HIV prevention activities. How should this budget be allocated? We review budget allocation rules employed by HIV prevention community planning groups, as well as other proposals and argue that such approaches do not appropriately represent the relationship between expenditures on HIV prevention activities and the results of prevention programs. We formulate the resource allocation problem that leads to preventing the maximal number of new HIV infections subject to a budget constraint, derive the implicit production functions that make existing rules optimal and argue that the resulting assumptions about the performance of prevention programs are untenable. We close by suggesting an alternative approach to allocating HIV prevention resources based on the principle of preventing the maximum number of new HIV infections subject to the prevention budget constraint. © 1998 Elsevier Science Ltd. All rights reserved

INTRODUCTION

This year, the federal government will allocate more than $600 million for HIV prevention [1]. The centerpiece of this effort is the HIV prevention community planning process. As part of this remarkable experiment in American democracy, the Centers for Disease Control and Prevention (CDC) distribute funds to 65 relatively autonomous community planning groups (CPGs) across the nation [2–6]. Each CPG shares with state and local health departments the responsibility to frame priorities and to monitor implementation of approved programs. This decentralized procedure seeks to accommodate local variation in HIV epidemiology, program effectiveness and social values. CPGs also provide influential blueprints for state and local governments to guide their own expenditures and HIV prevention efforts.

CPGs, thus, play a pivotal role in advising state and local health departments on how to allocate their HIV prevention resources. Although the CPG process has many virtues, we show that if one takes seriously the stated goal of HIV prevention, then existing and proposed approaches used to allocate HIV prevention budgets at the CPG level rely implicitly upon strong and, indeed, implausible assumptions. Our argument derives from formal analysis of the resource allocation problem faced by CPGs. We posit that CPGs seek to prevent as many new HIV infections as possible subject to a budget constraining HIV prevention resources. Given this objective, we determine the conditions under which commonly argued budget allocations are in fact optimal. These conditions amount to restrictions on the production functions for HIV prevention activities that are rather difficult to accept.

HIV PREVENTION COMMUNITY PLANNING

CPGs are intended to reflect the local communities affected by the HIV/AIDS epidemic, providers of HIV prevention programs and services, and local health officials and AIDS experts.

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Community planning activities are geared to the annual budget cycle. Through a process of needs assessment and local program review, CPGs provide recommendations to their local (typically state) health departments regarding the targeting of HIV prevention efforts.

CPGs seek to make systematic use of available medical research, HIV epidemiology, and social-science research to most effectively prevent new infections. CDC funding guidelines and other materials repeatedly emphasize "explicit consideration of priority needs, outcome effectiveness, cost-effectiveness" and scientifically grounded efforts to reduce HIV incidence [6, 7]. Many experts also hope that CPGs will encourage greater targeting of resources towards IV drug users and other high-incidence populations for whom prevention efforts are likely to be most beneficial and cost-effective [4, 6, 8–10].

Like previous community health planning efforts, CPGs encounter great difficulty in critically evaluating the efficacy and cost-effectiveness of funded interventions [11–14]. In reviewing the existing literature on HIV prevention community planning, we are struck by the widespread inattention to substantive outcomes and program evaluation, even as other central issues such as needs assessment are the subject of elaborate analysis and debate. Major studies [2, 5, 15–17] include detailed information on the *process* by which CPGs make decisions. Although concrete, measurable objectives are repeatedly emphasized in CDC materials [6, 7, 15], there is little evidence that CPGs develop or use such measures in their work.

BUDGET ALLOCATION RULES FOR HIV PREVENTION

How might one allocate HIV prevention funds? Not surprisingly, the 65 CPGs differ greatly in philosophy, organization, and technical sophistication. Because CPGs are so young, much of their time and creativity is devoted to the mechanics of the planning process itself: recruiting members and staff, establishing workable procedures for group decisions, beginning relations with local providers, government agencies and advocacy groups. Importantly, none of the 65 has yet implemented detailed program evaluation of funded efforts. Many have conducted formal or informal needs assessments to identify under-served populations or populations with high HIV incidence. Several CPGs plan to conduct "impact evaluations" to examine the actual provision of funded services.

Many CPGs are now searching for ways to allocate funds in light of known research findings and the advice of public health experts in the field. A few have begun to collect necessary data from public health departments and contractors to evaluate whether funded programs are achieving their stated goals. Understandably, the CPGs that show the most promise in these areas tend to be well-funded and to have stable professional staff. Massachusetts, for example, is developing a well-funded and analytically sophisticated approach to program evaluation. Despite such innovations, many CPGs employ rather ad hoc methods [2, 15, 17] that are perhaps no more justifiable than dividing the budget equally among competing program activities, or dividing the budget in proportion to the HIV infection rate, the number of AIDS cases, or some other such measure.

As an example, consider the method devised by Seattle-King County Department of Public Health. This approach is described verbally in Ref. [2]. Stated mathematically, their approach aims to determine x_i^*, the amount of money to be allocated to prevention activities targeting the i^{th} population subgroup (e.g. drug injectors, men who have sex with men, women at risk), from an available budget of B dollars. To determine these allocations, the population subgroups are first scored on each of the following four factors: risk group population; HIV prevalence within the population; riskiness of group behavior for HIV transmission; and the relative difficulty of providing HIV interventions in the population. Denoting the factor score in the i^{th} subgroup on the j^{th} factor by f_{ij}, an overall score S_i is computed for the i^{th} subgroup by multiplying the factor scores within the subgroup, that is

$$S_i = \prod_{j=1}^{4} f_{ij}. \tag{1}$$

The budget allocations are then made in proportion to these scores, yielding

$$x_i^* = \frac{S_i}{\sum_k S_k} \times B. \tag{2}$$

Such need-based approaches are perhaps useful for identifying populations that have been neglected by existing interventions. For example, the unique needs of disabled individuals might otherwise be overlooked. Such formulas also provide an organized way to assimilate the huge volume of information CPGs must consider. Despite such advantages, we are struck by the arbitrary and opaque nature of such formulations. Nowhere, for example is the likely impact or cost-effectiveness of available or proposed new programs taken into account. Such approaches are grossly incomplete without some accompanying description of the ability of proposed intervention activities to actually prevent infections as a function of resources deployed.

In the one published article we have found that does attempt to link expenditures to prevention effectiveness, the conclusion reached is that maximal prevention can be achieved by allocating all of the available resources to the group with the highest rate of new infections. Operationalized as a "spreadsheet model" and presented verbally with numerical examples by Kahn [10], the crucial assumptions and results become apparent via a mathematical statement of the model. Kahn assumes that the annual cost of prevention programs *per client* is constant at \$200 across *all* programs and that relative program effectiveness *per client* is also invariant and equal to a 10% reduction in risk behavior among those who receive prevention services. Kahn also assumes that there is no interaction across risk groups and that, within risk groups, there is no interaction between those receiving prevention services and those who do not. Let c denote the average prevention cost per client, f denote the fractional reduction in risky behavior per client that results from prevention and $H_i(f)$ denote the per capita number of infections that occur over the planning horizon among those in the i^{th} group who participate in prevention programs that reduce individual risky behavior by $100 \times f\%$. The specific model used to generate $H_i(f)$ is equivalent to the usual logistic epidemic model [18]. Note that by assumption, if x_i dollars are allocated to the i^{th} group, then x_i/c persons from that group receive prevention services. Since prevention benefits only accrue to those who participate in sponsored programs, the number of prevented infections in the i^{th} group when x_i dollars are allocated, denoted by $\Delta I_i(x_i)$, is given by

$$\Delta I_i(x_i) = \frac{x_i}{c} \times (H_i(0) - H_i(f)). \tag{3}$$

Kahn shows numerically that within his assumptions, the largest number of infections is prevented by allocating the entire budget to that group with the largest rate of new infections (i.e. the group with the largest value of $H_i(0)$). In general, of course, the optimal solution to this model would be to allocate all of the budget to that group with the largest value of $H_i(0) - H_i(f)$. However, given the epidemic model assumed, this latter quantity approximately equals $fH_i(0)$, explaining the result.

THE MAXIMAL PREVENTION PRINCIPLE

How might one judge the reasonability of existing or proposed rules for allocating HIV prevention resources? One approach consistent with resource economics is to postulate the objective such allocations are intended to attain and then ask what implied beliefs are required so that the stated allocations achieve the objective. We believe that the clear overiding goal of HIV prevention community planning is the prevention of HIV infections. Therefore, we take as a point of departure that the goal of allocating HIV prevention resources is in fact to prevent as many new HIV infections as possible subject to the prevention budget constraint. Doing so enables us to derive what one must believe regarding the effectiveness of public expenditures on HIV prevention in order for a proposed allocation rule to be in fact a good rule.

We thus offer the following model of HIV resource allocation. A CPG is faced with a budget of \$$B$ to allocate towards prevention activities across n predetermined subgroups of the population. Let I_i equal the rate of new infections that will occur in the i^{th} group absent any publicly funded intervention over the planning horizon and denote the amount of money allocated to prevention activities in the i^{th} group by x_i. Allocating x_i dollars to group i is, either implicitly or explicitly, believed to prevent $100 \times \alpha_i(x_i)\%$ of the infections that would have occurred in the absence of intervention over the planning horizon ($\alpha_i(x_i)$ assumed nondecreasing, $0 \leq \alpha_i(x_i) \leq 1$). This implies the belief that an allocation of x_i to group i serves to prevent $I_i\alpha_i(x_i)$ infections in that group. We refer to the functions $\Delta I_i(x_i) = I_i\alpha_i(x_i)$ as production functions, for the act of spending x dollars in group i "produces" $I_i\alpha_i(x)$ prevented new infections.

As the presumed goal is to prevent as many new infections as possible, the *maximal prevention principle* states that the dollar allocations to each group should be chosen to solve

$$\max_{\{x_1,x_2,\ldots,x_n\}} \sum_{i=1}^{n} \Delta I_i(x_i), \tag{4}$$

subject to the constraints

$$\sum_{i=1}^{n} x_i \leq B, \tag{5}$$

and

$$x_i \geq 0 \quad \text{for} \quad i = 1, 2, \ldots, n. \tag{6}$$

The resulting allocations serve to prevent as many infections as possible given the budget constraint.

The problem posed in eqns (4)–(6) is a *knapsack problem*, and can be solved for any proposed set of production functions using nonlinear or dynamic programming techniques [19]. Our intent, however, is to proceed in the reverse direction: given the infection base rates $I_1, I_2, \ldots, I_n$ and a budget allocation $x_1^*, x^*, \ldots, x_n^*$ that supposedly provides a solution to (4)–(6), what are the implied production functions (the $\Delta I_i(x)$'s) and are they reasonable?

PRODUCTION FUNCTIONS FOR CPG BUDGET ALLOCATION RULES

Consider the following four proposals for allocating the budget: split the budget equally among the n groups, allocate all of the budget to a single group as suggested in [10], allocate the budget in proportion to the rate of new HIV infections and allocate the budget in proportion to computed scores as, for example, illustrated by the Seattle-King County CPG [2]. For each proposal, what are the corresponding production functions that satisfy the maximal prevention principle?

Equal division among groups

The first proposal is simply to allocate B/n to each of the n groups. For an equal division of the budget to be optimal for *any* proposed budget, the production functions must satisfy the condition

$$\Delta I_i(x_i) = a_i + g(x_i), \tag{7}$$

where $g(x)$ is any increasing concave function and the a_i's are group-specific constants. Inserting eqn (7) into the resource allocation problem of (4)–(6) and solving establishes sufficiency, while substituting the solution $x_i^* = B/n$ for all i into the Karush–Kuhn–Tucker (KKT) conditions [19] associated with the optimization problem in (4)–(6) proves necessity.

Equal division requires believing that marginal program effectiveness is inversely proportional to the baseline rate of new infections. Consequently, it must be believed that prevention programs in subgroups where the incidence is relatively low are much more effective at the margin than programs in subgroups with high HIV incidence. This is not realistic, rendering equal division of the budget an inappropriate rule for maximally preventing infections.

All resources to one group

The second proposal is to give all of the money to one "favored" group. If the production functions increase linearly in x, as in Kahn's model, then the solution to the budget allocation problem will assign the entire budget to one group. Assuming linear production functions is a special case of a more general result: the budget will always be assigned in its entirety to some group i if and only if

$$\Delta I_i(B) - \Delta I_i\left(B - \sum_{j \neq i} x_j\right) > \sum_{j \neq i}[\Delta I_j(x_j) - \Delta I_j(0)]. \tag{8}$$

This condition must hold for all $B \geq 0$ and $x_j \geq 0$ such that $\Sigma_{j \neq i} x_j \leq B$ and follows directly from stating that it is always better to assign all B dollars to group i as opposed to any other allocation. Convex production functions (such as the linear functions assumed by Kahn [10]) can satisfy this condition easily, but convexity is not necessary. What is indeed necessary (and follows from eqn (8)) is

$$\Delta I_i'(x) > \Delta I_j'(0) \quad \text{for all} \quad 0 \leq x \leq B \quad \text{and} \quad j \neq i, \tag{9}$$

where $\Delta I_i'(x) = \mathrm{d}\Delta I_i(x)/\mathrm{d}x$. This says that the marginal number of infections prevented in group i at any resource level must exceed the marginal number of infections prevented by initiating prevention activities in any other group. This condition may be reasonable for small-scale, budget-constrained situations in which saturation effects are negligible, or where fixed-costs associated with the "disfavored" groups are prohibitive. The optimal allocation of resources could well be lopsided under these conditions, rendering an overly even allocation of very small budgets suspect in such cases.

It is difficult to argue that condition (8) holds for large values of B, however, for the start-up costs for interventions targeting new groups become a smaller fraction of overall expenditures on the one hand, while saturation effects in the "favored" group take hold on the other. As an example of the latter, the marginal cost of recruiting clients to outreach prevention programs is probably an increasing function in the number of clients recruited thus far, for such programs tend to access clients from the easiest to the most difficult to reach [20]. At some point of investment, diminishing returns would force the marginal preventive impact of the favored program activities to approach zero (even though the average cost per infection prevented still looks attractive). But, if this is so, then the marginal preventive impact of any other program *at initiation* would have to approach zero on account of condition (9), an untenable consequence.

Allocation in proportion to baseline infection rates

Proportional allocation by infection rates implies that the amount of money allocated to group i is given by

$$x_i^* = \frac{I_i}{\sum_j I_j} \times B, \tag{10}$$

for *any* budget B. To satisfy the maximal prevention principle, the production functions must be equal to

$$\Delta I_i(x) = a_i + kI_i \log(x), \tag{11}$$

for group-specific constants a_i and some common positive constant k. Again, sufficiency is established by substituting eqn (11) into the resource allocation problem of (4)–(6) and solving, while necessity follows by substituting eqn (10) into the KKT conditions.

Allocating in proportion to the recent infection rate requires a different extreme in assumptions, namely, that relative effectiveness grows only logarithmically with available funds. This implies that most of the incremental benefits from prevention are achievable from initial expenditures. For example, if $\alpha(x) = k \log(x)$ (with x measured in dollars), and if \$3 million dollars could be allocated, spending only \$675,000 would achieve 90% of the benefit from spending all \$3 million. Such diminishing returns seem extreme.

ALLOCATION BY PROPORTIONAL SCORES

The analysis for allocation by proportional scores follows in similar fashion. This rule divides the budget by assigning

$$x_i^* = \frac{S_i}{\sum_j S_j} \times B, \tag{12}$$

to group i, where S_i represents the score computed for group i.

Equation (12) can satisfy the maximal prevention principle for *all* possible scoring schemes and budgets if the infection rates in the different population subgroups are proportional to the group scores that is, if for some constant K

$$I_i = K \times S_i, \tag{13}$$

and if the relative production functions are logarithmic as stated in eqn (11). Considering the Seattle-King County model, it is difficult to believe that the product form of eqn (1) represents a credible model for the rate of new HIV infections. The same holds true for other scoring systems we have reviewed [15, 17]. This, together with the assumption that program effectiveness grows logarithmically with dollar allocations, renders allocating the budget by proportional scores suspect as well.

IMPROVING THE RESOURCE ALLOCATION PROCESS

The problem with current approaches to allocating HIV prevention resources lies in the failure of these approaches to appropriately capture the relationships between HIV prevention effectiveness and expenditures on HIV prevention activities. With the exception of Kahn's recent paper, none of the procedures we have reviewed makes any attempt to link program performance to the resulting budget allocations.

An alternative proposal is to reorient HIV community planning around the maximum prevention principle. The maximum prevention principle, we feel, provides an appropriate touchstone for evaluating HIV prevention efforts. This principle illuminates the tradeoffs involved in funding competing programs and reminds CPG participants of the real costs of inefficient resource allocation.

Kaplan [4] has argued how such a process could proceed. Rather than rush to recipe-like allocation formulas, Kaplan's proposal challenges CPGs to pursue two distinct tasks. The first is to agree upon estimates of the baseline rate of new HIV infections in the groups in question. Several methods exist for producing such estimates, including backcalculation [21], "snapshot samples" based on immunological markers of infection [22, 23] and "components models" [24].

The second, more difficult, task is to subjectively estimate the production functions $\Delta I_i(x_i)$ for prevention activities among different population subgroups. The proposed approach is to focus on subjectively estimating the relative effectiveness of programs $\alpha_i(x)$ having already estimated the baseline rates of new infections. Doing so is similar in spirit to subjectively estimating utility functions.

Having completed these two tasks, it is then possible to directly apply the maximal prevention principle to obtain the (subjective) optimal allocations. It is also possible to include additional political and/or pragmatic side constraints with this approach once the production functions have been constructed. Kaplan [4] presents a detailed example of this approach.

Whether approached subjectively or perhaps more empirically via improved evaluations of HIV prevention programs that incorporate the economic features of program operations and performance [20], there is clearly a gap between HIV prevention research and the utilization of this research in allocating HIV prevention resources. This is particularly unfortunate, for deciding upon the actual dollar deployment of HIV prevention monies to alternative activities is arguably the most important set of decisions regularly exercised in HIV prevention policy. More efficient allocations will not only please health economists. Rationally allocating the HIV prevention budget will also save more lives.

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