ISSUES IN THE ANALYSIS AND DESIGN OF THE EXPERIMENTAL PORTION OF THE HEALTH INSURANCE STUDY

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Introduction and Objectives

In this paper I discuss some selected issues in the design and analysis of the experimental portion of the Health Insurance Study.[1] The objectives, methods of procedure, and significance of the experimental portion of the Study are discussed in Newhouse (1974); those desiring a general overview of the project are referred to that paper. In this paper I first briefly review the objectives of the experiment for those who do not wish to read the longer paper. I then discuss two problems which will have to be faced when analyzing the data from the experiment, and the implications those problems have for the design. In line with the chairman's charge to discuss "methodological questions, issues, and constraints," I have chosen problems whose solution will require breaking new ground; in neither case do I feel we have reached a definitive answer. I conclude by discussing three statistical design problems we have had to solve.

Stated at the most general level, the objective of the experiment is to advance the state of knowledge concerning the consequences of alternative ways of financing medical care services. We seek to measure own- and cross-price elasticities (insurance elasticity) of demand and their interactions with income. Measurement of price elasticity is a necessary condition for predicting utilization and cost under any particular insurance plan, and if the supply of services is perfectly elastic in the long run, it is sufficient to predict how insurance will affect the share of the nation's resources devoted to medical care. Measurement of the interaction of price elasticity with income will determine the distributional effects of any particular financing plan. In those plans which require out-of-pocket payments on the part of the consumer, we have designed the plan so as to limit his maximum out-of-pocket loss to a certain percentage of his income, since this is a potential policy option. The maximum out-of-pocket loss is called the Maximum Dollar Expenditure (MDE). Thus, price elasticity is to be measured within the context of this type of plan.

We also seek to measure, as best we can, the effects of alternative financing arrangements on health status. Whereas our first goal, the measurement of price elasticities, may be thought of as relating to the costs of a financing method, this second goal can be thought of as measuring certain of the benefits.

A third goal relates to understanding the consequences of increasing the demand for ambulatory services. Analysis shows that a national health insurance plan could cause a substantial disequilibrium in the market for outpatient physician services. This in turn could lead to the activation of several kinds of mechanisms to equilibrate the market, including price increases, queuing, delays to appointments, change in case-mix seen by physicians, changes in revisit rates, and so forth. The extent to which each of these mechanisms operates will play an important role in determining who gets what kind of service for what kind of medical problem. We seek to provide some information on how the burden of adjustment is distributed among these mechanisms.

A fourth goal is to measure the effect of prepaying the physician for his services rather than paying him on the basis of fee-for-service. A fifth goal is to find out how much additional private insurance families would buy if there were a public plan which required out-of-pocket payments for services (as Medicare does, for example). Finally, we wish to learn as much as possible about the administrative problems and rules of operation which arise in health insurance plans, particularly those which have income-related clauses.

In order to estimate the effect of price on utilization and health status, we have structured an experiment which will give various health insurance plans to approximately 7,500 individuals (in 2,000 families) in four sites.[2] The insurance plans are structured so that the families pay a percentage of their bill which varies from zero to 100 percent. As mentioned above, if the family must pay something out-of-pocket, its expenditures are limited to a certain fraction of its income; the fraction varies as an experimental treatment; it is either five or fifteen percent. In some other plans all outpatient care is free, but the family must pay a specified fraction of inpatient expenditures. Also, some individuals are to be enrolled in a Health Maintenance Organization, in which the physicians are prepaid.

Observations on the utilization of the participants should establish the price elasticity of demand, as well as the effect of prepaying the physicians. The effect of insurance on health status is extremely difficult to assess because of the difficulty of measuring health status. In order to measure self-assessed health status, all of the participants will take quarterly interviews; all of them will also take screening type physical examinations at the end of the experiment to measure "objective" health status; some participants will take initial physical examinations.[3]

Measurement of the consequences of a disequilibrium in the market for ambulatory services is accomplished by selecting sites in which the physicians' workload varies. While the range of variation in workload across communities may not include the workload which would be observed if free ambulatory coverage were instituted, it is the only method within the context of the experiment to obtain information on this important question.

The degree to which families will supplement not very generous insurance will be measured by permitting supplementation in the final year of the experiment. By that time we will have an estimate of the actuarial value of the policy; we intend to offer supplementary insurance at varying rates in order to test the effect of alternative tax treatment of health insurance premiums. Such premiums are not now taxable income if paid by the employer, but it has been proposed that this treatment be changed.

Some Issues in Analyzing Data from the Experiment

A principal issue which the analyst of the experimental data will face is the treatment of price, given that price falls with total expendi-

ture because of the MDE. As a result, traditional methods of analysis are inappropriate. Prior work in the field of medical demand analysis and demand analysis more generally has tended to analyze consumption (either measured in dollars or in physical units) per unit of time as a function of price. In these analyses price per unit is assumed to be constant. The theory underlying these analyses is standard economic theory, which assumes that the consumer optimizes, such that he values the marginal unit at the marginal utility of income foregone to purchase it. With the MDE, however, there are two local optima, as shown in Fig. 1. Fig. 1 shows a two-commodity world of medical care and all other goods; I_1 and I_0 are indifference curves.[4] The kinked line is the budget line; after the consumer has consumed L units of medical care, he does not have to sacrifice more of other goods to obtain care. (The budget line is net of any taxes of premiums the consumer has paid to finance the insurance policy.) There are two local maxima, at A and B; in this diagram B is clearly the global maximum.

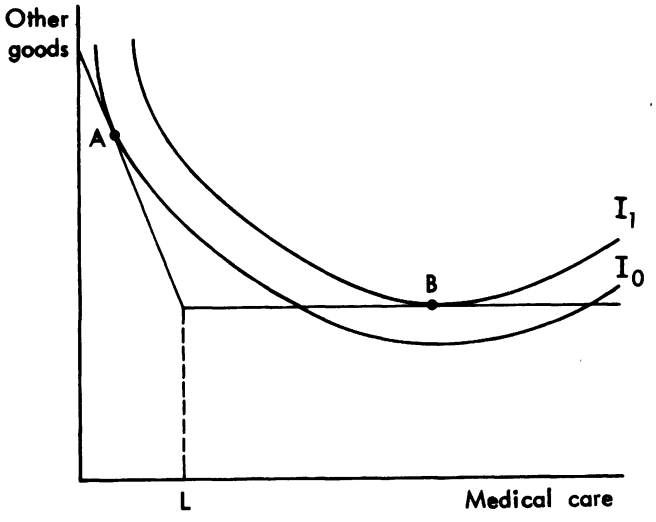

Figure 1

The problem caused by the kinked budget line, while somewhat novel from the point of view of empirical demand analysis, is reasonably tractable. Consumers can be assumed to have a utility function of a specified kind; then by observing expenditure choices, one can infer the parameters of the function.[5] Knowing the function, one can predict the consequences of any price structure.

What makes experimental data difficult to analyze is that the consumer will typically face several choices during the expenditure accounting period, none of which taken singly could cause him to exceed the deductible, but all of which together may. Thus, when making his initial choices, the consumer is operating under uncertainty about what the marginal price at the end of the accounting period will be.

Our plan for modeling this situation is to associate all expenditures with an illness episode.[6] We try to explain an individual's expenditures on each illness episode using as explanatory variables the insurance plan the consumer has, the consumer's expectations regarding expenditures on this episode and future expenditures, the amount of expenditure the consumer must make before his coinsurance rate changes, and a set of demographic variables such as income. We separate expected expenditures on this episode and expected expenditures on future episodes, because the consumer has information about this episode when he begins therapy which he does not have about future episodes. Expenditures on this episode are a function of diagnosis (using extraneous data),[7] and expenditures on future episodes are a function of the individual's age, sex, general health status (including any chronic conditions), and so forth.[8] The theory underlying an episodic model is discussed at length in Phelps (1973), although Phelps does not treat the case of a price which falls with expenditure.

The resulting equation (together with an error term) generates a distribution of expenditure per episode per individual; there is also a distribution of episodes which the experimental data will generate. If these distributions are analytically tractable, they can be convoluted, and mean individual expenditure per year (or other accounting period) predicted. If they are not analytically tractable, a simultion can be performed to predict mean expenditure per year. If there are family related clauses in the insurance plan (for example, family deductibles), individual expenditures must be aggregated to the level of the family.

The problem of price per unit falling with quantity and the proposed solution of analysis by episode have several implications for the design. The most obvious is that data must be gathered which permit us to define illness episodes and link medical services to them. This implies a degree of cooperation on the part of the physicians in filling out claims forms; it also implies assuring ourselves that the application of the definition of an episode is reliable. A second implication is to minimize the number of discontinuities or kinks in the price line in order to simplify as much as possible modeling the uncertainty which the consumer faces. This has been done by limiting all plans to at most one change of price; that is, there will be one coinsurance rate which will apply to family expenditures until expenditures have reached a certain percentage of family income, after which there is no coinsurance. (There is no plan with a deductible followed by a non-zero coinsurance rate, followed by some other limit.) A third implication is to stipulate that there be no carryover of unreimbursed expenditures from one accounting period to another. At one extreme there could have been a moving average accounting period; this would mean there would be no coinsurance so long as the rate of expenditures exceeded a certain amount. Besides creating a perverse incentive to consume services (unless based on the rate of unreimbursed expenditure), this arrangement would be extremely difficult to analyze. A modification of this, which was considered at some length, was to permit carryover of unreimbursed expenditures occurring at the end of the accounting period to the next accounting period. The intent of this is to prevent someone from having to satisfy an expenditure limit twice in the same illness episode, which could happen if the episode occurred near the end of a fixed accounting period. While conceptually straightforward, it was felt that the empirical complications such a clause would introduce were

not worth the value of having it.

The final implication of episode analysis for the design is that the design should provide a hedge, if episodic analysis proves infeasible. The hedge is that an analysis of covariance model (basically estimation of means across plans adjusted for demographic differences) should yield reasonably precise estimates of a few dissimilar plans. This can be done by minimizing the number of plans. There are now 16 plans and around 8,000 family years to be allocated to them. Our estimates are that this should yield estimates of the effects of insurance to within plus or minus 10 percent or so (Newhouse 1974). If, however, episodic analysis proves infeasible, sequential design will permit even greater concentration of families among a smaller number of plans. The current time schedule calls for fifty families to begin as a pilot sample on January 1, 1974. If all goes well, enrollment of the next 500 families will take place in late summer of 1974, the next 500 families nine months later, the next 500 families six months later, and the last 500 families three months after that. As a result, concentration of families in a few plans will be feasible should it prove necessary.

A second set of analytical issues arises in connection with supplementary behavior. These issues concern the design and analysis of the supplemental portion of the experiment. At what terms should supplementary insurance be available? Should both positive and negative supplementation be permitted? Should an individual be allowed to vary his coinsurance rate, his expenditure limit, or both? What is the dependent variable for analysis and what are the explanatory variables? We next discuss these questions in turn.

Since the overall objective is to understand the demand for supplementary insurance, the terms at which such insurance can be purchased will reflect the rates at which it would be available in the marketplace, if a national plan were enacted which resembled our plan. Therefore supplementation will be permitted at different premiums, reflecting both the tax treatment of insurance premiums and various loading charges. Insurance premiums are not now taxable income if paid by the employer, which means there is a subsidy equal to the marginal tax rate from the purchase of insurance. Loading charges vary from 100 percent for some individual insurance to 6 percent for individuals in the largest group. We will offer insurance at a small number of loading charges, ranging from 100 percent down to minus 30 percent or so, reflecting a tax subsidy and a very low loading. The actuarial value will be adjusted for the age and sex mix of the family, since the private market is likely to take account of such differences.

No decision has been made on whether both positive and negative supplementation will be allowed. If negative supplementation were not allowed, an individual could purchase more generous insurance, but not less generous.[9] To allow positive supplementation is sufficient to provide data on the degree to which individuals would purchase additional insurance if the government mandated a particular plan. To allow both positive and negative supplementation is to attempt a broader study of the demand for insurance. If negative supplementation is allowed, nothing is sacrificed in terms of measuring what would happen if only positive supplementation were allowed (since anyone who negatively supplements would just be assumed not to supplement if such were not allowed). However, negative supplementation raises an ethical and a practical issue, because allowing negative supplementation on the basis of actuarial value raises the possibility that an individual could be ex post worse off.[10] (For example, an individual with full coverage who chose to change to $500 deductible and received, say, $200 representing the actuarial value of the difference, could have a bill of $500.) If an individual were to be worse off ex post, it would usually be to his advantage to withdraw from the experiment and return to his old insurance. Current HEW guidelines on research with human subjects require that withdrawal be permitted. Withdrawal under these conditions would obviously defeat the experiment. In order to prevent withdrawal, one can make lump sum payments to those who have generous insurance plans in an amount large enough to compensate them for their worst case.[11] Whether this is sufficiently expensive so as not to be worthwhile depends upon the actuarial values involved; the higher the actuarial value, the less must be paid for worst case compensation. As noted above, no decision has yet been made on negative supplementation.

Given that positive supplementation at least will be allowed at various loading charges, the question arises as to what kind of supplementary behavior should be permitted. The tentative answer to this question is that individuals should be permitted to choose coinsurance rates of 0, 25, or 50 percent, and that they should be allowed to set their MDE at 5 percent of income. (The zero coinsurance rate is equivalent to a zero MDE.) The basic reason for allowing variation in both dimensions (coinsurance and MDE) is that the private insurance market would offer such variation, and it is important to understand how much each dimension is varied, since there may be different implications for demand, according to which dimension is varied.

Choice of explanatory variables will be based on theoretical work related to consumer choice of insurance; unfortunately, this literature is not yet very far advanced.[12] Nevertheless, it is clear from the work which has been done that the consumer's choice will be a function of the distribution of the consumer's expected expenditures, his permanent income, and the price of supplementation. Depending upon these variables, the consumer chooses an optimal MDE-coinsurance pair from the pairs that are open to him. Each of the two dimensions of choice will be analyzed separately. While the choices in each dimension are interdependent, theory is not powerful enough to specify restrictions which exclude a variable from one equation and not the other. Hence, structural equations are not identified and only a reduced form equation will be estimated. Since the choice of supplementary insurance which we have structured is discrete, methods developed by Nerlove and Press (1973) for estimation with polytomous dependent variables will be used.

An alternative to analyzing choice of MDE and coinsurance is to analyze the risk which the consumer leaves himself bearing. Provided suitable

measures of risk can be found, this offers the possibility of testing hypotheses related to risk-bearing behavior. Analysis of risk per se, however, is not sufficient for policy purposes, since there may not be any convenient way of moving from a measure of risk to a unique structure of insurance. The structure is important for policy purposes, since it will affect demand (except in special cases). Even if there were a way to move from risk to a structure, it appears more efficient to work directly with the structure, if that is what one is interested in. A similar argument can be made for not measuring supplementation by the amount of the supplementary premium that the consumer pays.

Issues in Statistical Design

Among the many possible issues in the statistical design of the experiment, four will be discussed here. These are the choice of the number of individuals to be assigned to any particular plan, selection of participating individuals from the community, allocation of those individuals to plans, and choice of sites in which to experiment.

The number of individuals to be assigned to any plan will be determined by use of the Conlisk Watts model developed for the New Jersey Negative Income Tax Experiment (Conlisk-Watts 1969). This model assumes that one is interested in estimating a vector of coefficients β in a model:

$$y = X\beta + \varepsilon, \text{ where } E(\varepsilon) = 0 \text{ and } V(\varepsilon) = \sigma^2 1. \quad (1)$$

The estimator of β is:

$$b = (X'X)^{-1} X'y, \; V(b) = \sigma^2 (X'X)^{-1}.$$

The admissible regressor rows of X are specified and consist (in our case) of prices (as determined by insurance plans) or a set of dummy variables for insurance plans (in an analysis of covariance model). A budget constraint is assumed and cost per regressor row (insurance plan) is given. The model then chooses the number of observations to be assigned to any design point such that

$$\phi = tr(WV(Pb)) \text{ is minimized,} \quad (2)$$

where W is any vector of weights and P is any arbitrary set of vectors, but most frequently equals either I or X.

Apart from specifying W and P, the major issue to be resolved in this step is the choice of X. Within this issue there are in turn two subissues. One is the choice of plans, or equivalently, the admissible rows of X. Since the model is free to allocate no observations to any design point, this choice really concerns which design points are constrained to have no observations assigned to them. The second is the issue of what functional form to choose.

Choice of design points can be thought of as first determining the number of design points which are not constrained to be zero (that is, determining the maximum number of insurance plans) and then determining what those design points are. While constraining fewer points to be zero will lead in general to a smaller value of ϕ, there are two costs to considering larger numbers of design points. The first is a computational cost. The second follows from the desire to hedge, discussed above, by maintaining the viability of the analysis of covariance model. More design points degrade the precision of this model. As mentioned above, there are initially sixteen design points; they are described in Newhouse (1974).

Several possible functional forms will be considered. It is envisioned that a decision-theoretic approach to choice of functional form will be used, so that functional form will be chosen which minimizes expected loss. (See Conlisk-unpublished)

A secondary issue related to the design of plans is the possibility of truncating the MDE in order to achieve greater efficiency in the estimation of price elasticities. Truncation may represent a gain because the method of reimbursing families generally requires that they receive a lump sum equal to their MDE. The question then arises: What is the value of an absolute dollar ceiling on the MDE? This has the effect of eliminating price variation in certain high ranges of expenditure, while increasing the budget available to allocate to lower ranges of expenditure. The optimal amount of truncation therefore depends on the relative interest in the estimation of elasticities at different levels of expenditures. We have structured this problem so that the Conlisk-Watts model may be applied to it. Rows of the X matrix will be created representing plan-total expenditure pairs. We then associate with each plan-total expenditure pair the conditional probability of that observation, given that the individual is assigned to that plan. The constraint is then placed on selection of regressor rows that all rows associated with a particular plan must be selected if any are. The MDE (together with any truncation factor) enters the model as changing the costs of an insurance plan as well as the probabilities of obtaining expenditures in various intervals. By running the model with alternative MDEs (and given weights for expenditure-elasticity interactions), one obtains a set of truncations which minimizes ϕ. For example, the optimum might be the lesser of 15 percent of income or $1,200 in the 100 percent coinsurance plans, but the lesser of 15 percent of income or $600 in the 25 percent coinsurance plan.

Individuals will be chosen for this experiment by means of the Finite Selection Model (FSM) developed by Morris for this experiment (Morris, forthcoming (a)). This model is similar to the Conlisk-Watts model in its objectives, but quite different in its underlying assumptions. The Conlisk-Watts model assumes that the regressor rows (the rows of the X Matrix) come from discrete space, but that there is an infinite population to sample from. This assumption is appropriate for selection of treatments, but much less so for selection of families. By contrast, the FSM assumes that the regressor rows may come from continuous space, but that there is a finite population to sample from. For example, individuals have associated with them a vector of demographic characteristics which are continuous or nearly so (age, family, size, income, education, for example). There are, however, only a finite number of possible individuals to choose to participate.

More formally, the FSM assumes that one is interested in estimating equation (1) from a subset of size n of all N available families, $n < N$. The objective function is given by (2). If there are n observations, (2) can be rewritten as:

$$\phi_n = \text{tr } D(X'_n X_n)^{-1} = \text{tr} DS_n \ , \qquad (3)$$

where the subscript n indicates that there are n rows in X, and D equals P'WP. Suppose an $(n+1)^{st}$ observation is to be added which reduces ϕ_n as much as possible for its cost. That is, we wish to maximize

$$(\phi_n - \phi_{n+1}(x))/c(x) \ , \qquad (4)$$

where ϕ_{n+1} is conditional on using an X matrix equal to $\begin{matrix} X_n \\ x' \end{matrix}$ and x' is a row vector of characteristics of the $(n+1)^{st}$ family. c(x) is the cost of a family with characteristics x. An algebraic identity gives

$$S_{n+1} = S_n - \frac{S_n x x' S_n}{1+x'S_n x}$$

Hence,

$$\phi_{n+1}(x) = \text{tr} DS_{n+1} = \text{tr} DS_n - \frac{\text{tr} DS_n x x' S_n}{1+x'S_n x}$$

$$= \phi_n - \frac{\text{tr } x'S_n DS_n x}{1+x'S_n x} = \phi_n - \frac{x'S_n DS_n x}{1+x'S_n x} \ ,$$

since $x'S_n DS_n x$ and $x'S_n x$ are scalars.

Substituting, (4) equals:

$$\frac{x'S_n DS_n x}{c(x)\ [1+x'S_n x]} \ .$$

Given a list of unchosen individuals, (5) may be computed for each x and the maximizing x chosen. The procedure can be repeated until n is such that

$$\sum_{i=1}^{n} c_i = C,$$

where C is a budget constraint.

The stepwise algorithm implied by the successive use of (5) has in our experience led to an optimal, or nearly optimal, set of families, but did it not do so, substitutions and corrections could be applied at the end of the selection by using a similar algorithm until a satisfactory list is obtained. While the literature contains no discussion of the use of this algorithm on the ϕ objective function in this context of costs and variances, there is experience and theory for using a related algorithm to determine "D-optimum" subsets (choosing subjects to maximize det $|X'_n X_n|$), and the experience there has been favorable (Harville (1973), Johnson (1973), Mitchell (1973), Wynn (1972)).

While the FSM will be used to choose the families which will participate in the experiment, we will "randomly" allocate the families to experimental treatments (plans) and the control group.[13] While the FSM can, in principle, select optimal family-plan combinations (given a model to be estimated), random allocation offers some protection against latent variables. (That is, one can be reasonably sure that any such variable will be balanced among the treatment groups.) By allocating randomly one pays a price in efficiency of estimation (if there are no latent variables). The price paid can be kept small if random allocation is made subject to a constraint of near orthogonality between the demographic and plan variables, ensuring near balance among the treatment groups.[13]

The Conlisk-Watts model and the FSM may also be applied to site selection. Morris has proposed a generalization of the Conlisk-Watts model which can be used to determine the optimal number of sites, given that there are fixed costs of operating in each site (Morris, forthcoming (b)). We assume a random effects model for city-specific coefficients $\beta_i \sim N_k(\beta, T)$, where k is the dimensionality of the β vector. T is therefore the between-city variance-covariance matrix. For simplicity assume that the same design points are to be used in each city and that the cost of a design point does not depend on city. The model then minimizes:

$$V = \text{between site variance} + \text{within site variance} = (1/K)(v + \phi), \qquad (6)$$

subject to

$$C = K(C_0 + \sum_{j=1}^{m} c_j n_j) \ , \qquad (7)$$

where there are K sites, $v = \text{tr}(DT/\sigma^2)$, ϕ is defined by (2) for the observations within each site, C_0 is the fixed cost of operating in any site (for opening an office, running a field staff, and so forth), c_j is the cost of an observation at the j^{th} design point (or insurance plan) and n_j represents the number of observations at the jth design point in each city.

The solution to this problem is quite simple. Define $C_K = (C_T/K) - C_0$ as the amount per city available to spend on design points after paying the fixed costs per site C_0. Then, following the standard Conlisk-Watts procedure, minimize (2) subject to a budget constraint of C_K. This defines $\phi^{(K)}$, where the superscript indicates that ϕ depends on K. The optimal K is that integer K* which minimizes $(1/K)(v + \phi^{(K)})$ and can be determined by enumeration in our case.

After determining the optimal number of cities in this fashion, we plan to use the FSM to select actual cities. The variable of interest across cities is the workload of physicians; the FSM will tend to select extreme values. A city-specific cost index will also be entered in the FSM, so that it will tend to select cheaper cities. The first site is Dayton, Ohio; the second site will be in the West and the third site in the South. No decision has been made on the location of the fourth site.

NOTES

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ment. The author would like to acknowledge the assistance of Carl Morris on the issues discussed in the last part of the paper.

2. There is also a control group who remain on their existing insurance. Their purpose is described in Newhouse (1974).

3. Some of the participants will not receive an initial physical in order to measure the effect, if any, of the physical on utilization.

4. The only unusual thing about them is that they turn up, indicating that the consumer has negative value for certain levels of medical care consumption. This may be because it takes increasing amounts of time (assumed to have increasing value) to consume more care or because sufficient exposure to medical care may actually decrease health status, through increasing the risk of infection or iatrogenic disease, relative to the possible benefits of care.

5. This suggestion has been made by Kenneth Arrow.

6. There are two types of episodes. An acute episode represents the consumer's response to a random loss of health stock; an acute episode in general will terminate within a relatively short period of time, either because the underlying pathology is self-limiting or because medical intervention has cured the problem. A second type of episode is chronic; a chronic problem in general requires medical intervention to maintain a stock of health and is not expected to terminate. The chronic episode therefore lasts for the entire accounting period. (A chronic condition in remission which "flares up" will be treated as an acute episode.) For analytical purposes it differs from an acute condition in that expenditures may be assumed to be better foreseen.

7. We will estimate expected expenditure by using mean expenditure for that diagnosis (if possible mean expenditure conditional on a particular plan). This implies we must measure the incidence of episodes for which no care was sought, which we will attempt to do in quarterly interviews.

8. If possible, generalized least squares will be used to allow for non-zero covariances among family members.

9. For example, an individual with a policy with a $1000 deductible who was being paid $1000 could change the deductible to $500 and be paid $800, but an individual with full coverage would not be allowed to choose a deductible of $500 plus $200, if that were the actuarial value of the difference between a full coverage policy and one with a $500 deductible.

10. To allow negative supplementation of not generous plans also raises the issue of accurate calculation of actuarial values; we will not be well placed to determine, say, the actuarial value of increasing a deductible from $1000 to $2000.

11. These payments may be held in an escrow account and made conditional on completion of the experiment.

12. Theoretical beginnings may be found in Arrow (1973a, 1973b), and Phelps (1973).

13. The idea contained in this paragraph was suggested by Bradley Efron.

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