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ON RISK DEDUCTIONS IN PUBLIC PROJECT APPRAISAL

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Project appraisal under uncertainty should, in general, be worked in terms of carefully computed expected or mean values of uncertain elements. The major exceptions are when: (a) project returns are large relative to national income; or (b) project returns are highly correlated with other national income. Approximate procedures have been developed for computing risk adjustments in each of these special cases singly, but here, a more comprehensive procedure is described that encompasses both cases separately and jointly.

Introduction

For more than 20 years a vigorous, and probably still unfinished, debate has raged over the importance, or otherwise, of allowing for uncertainty in appraisal of public investments. Early polar positions were that public investments should be discounted at (risky) market rates, so that investment patterns are not distorted (Hirshleifer 1965, 1966; Pauly 1970) or at the riskless rate, because government can effectively pool risks into unimportance through its large and diversified portfolio of investments (Samuelson 1964; Vickrey 1964).

The argument was advanced significantly through introducing the notion of sharing of public risks by members of society, in the signal contribution of Arrow and Lind (1970). In a stylised world of (statistically independent risky projects, they demonstrated that, when the risks are publicly borne (i.e. shared), the total cost of risk bearing is insignificant and, accordingly, governments should ignore uncertainty in appraising public investments. Therefore, the appropriate discount rate is independent of considerations of risk.

The controversy thus fuelled has yet to run its course. Although the central result of Arrow and Lind (1970) has not been successfully challenged (see e.g. Gardner 1979 vs Bird 1982, and the recent assault of Rustagi and Price 1983), the setting and its relevance, and the interpretations that should be made, have often been questioned. Mishan (1972) took Arrow and Lind to task for what he saw as questionable use of the Kaldor-Hicks criterion of social improvement, and argued that, when public investment is possible in the private sector, the relevant opportunity cost of public funds is the 'full actuarial rate of return' (p. 163). Use of a (lower) riskless rate of return in public appraisals would, he contended, deny potentially larger growth.

McKean and Moore (1972) quibbled, seemingly erroneously, with how large the number of people sharing risks needs to be for the Arrow and Lind result to hold. The criticism of Nichols (1972) was more cogent. Echoing Mishan (1972), he emphasised the dependence of the opportunity cost (and thus the rate of discount) of public funds on the size and disposition of such funds. This theme was again taken up by Sandmo (1972). In concluding (along with Hirshleifer 1965) that public-sector discount rates should always include a margin for risk corresponding to that for comparable private investments, he stressed that the difference from the Arrow and Lind conclusion centred on the different assumption made about the (non-) independence of returns from public projects. He, along with Fisher (1973), also addressed the irrelevance of the Arrow and Lind result for projects producing *pure* public goods, whose risks do not get spread into obscurity.

One useful clarification of the Arrow and Lind idea is that of James (1975). She noted potential inconsistencies between piecemeal and global appraisal of projects using the risk-spreading theorem unless, in appraising a group of projects as a group, the risk pooling effects (Samuelson 1964; Vickrey 1964) provide sufficent gains in risk reduction through diversification.

With Arrow and Lind (1972) unrepentant, and in spite of some refinements elaborating the nature of income taxation as a social risk-sharing mechanism (Mayshar 1977 but see also Stewart 1979 and Mayshar 1979) and more realistic specification of the fiscal (Foldes and Rees 1977) and financial (Makowski 1983, p. 320) systems of an economy, this is essentially where the issues are becalmed in the controversy over discount rates in public projects. Meantime, however, authors with the more overtly practical purpose of providing guidance to project appraisers had been developing, largely independently it seems, procedures for grappling with uncertainty in appraisal. The topic was explored by Reutlinger (1970, pp. 52-3), but was taken up more comprehensively in the works now to be reviewed.

Approaches to Risk Adjustments

The authors of the UNIDO (1972) *Guidelines* kept the argument simple in defending as normal practice the use of expected net present value, *E*[*PV*], evaluated at the (riskless) social rate of discount. They did note some 'exceptional cases' (p. 111) which were resolved by introducing a concave (risk-averse) utility function for national consumption:

(a) an unusually large project, where benefits are a substantial fraction of national income; and
(b) where national income is uncertain, and project benefit is correlated with (i.e. not independent of) national income.

Both these exceptions depart from the key assumptions underlying the Arrow and Lind (1970) results. The UNIDO illustrations pointed to the likely small deduction from *E*[*PV*] occasioned by large-project effects but to the potentially significant adjustments involved in accounting for correlation effects. These can be in either direction. For instance, a project with a strong *negative* correlation with national income (such as, say, a major flood-control and irrigation project in an agrarian economy) may have a certainty equivalent benefit in excess of *E*[*PV*]. Conversely, projects positively correlated with national income will be analogously discounted for uncertainty.

Little and Mirrlees (1974) offered advice remarkably similar to that of UNIDO (1972), generally in the spirit of Arrow and Lind (1970), and catalogued several further 'more difficult cases' (p. 316) when social *E*[*PV*] may be inadequate as a criterion. Concave utility functions were also used by Little and Mirrlees to develop useful pragmatic approximations to assist planners in computing risk-adjusted (approximate certainty equivalent, $\hat{X}$) values for project benefits. Their formulae feature a dimensionless coefficient of relative risk aversion, A, that is intuitively reasoned to be in the range 0 to 4, probably about 2. It would be unity if the utility function were logarithmic. Some sample evidence from farmers in Nepal suggests that higher values (say about 4) may be more appropriate for low-income groups (Hamal and Anderson 1982).

The two key approximations are based on severely truncated Taylor series representations and are presented here in a form that highlights the coefficient of variation. The first is a second-order approximation for the 'large project' case:

$$\hat{X} \doteqdot E[X]\{1-(A/2)\,C[X]^2 E[X]/\mathrm{E}[Y]\}, \tag{1}$$

where X is the certainty equivalent value of the random benefit X;
$E[\;]$ is the expected value operator;
$V[\;]$ is the variance operator;
$C[\;]$ is the coefficient of variation operator
$C[X] = V[X]^{0.5}/E[X]$; and
Y is national income.

The second is a first-order approximation for a project mutually dependent with income:

$$\hat{X} \doteqdot E[X]\{1 - A\rho_{xy}C[X][C[Y]\}, \tag{2}$$

where ρ_{xy} is the simple correlation between X and Y; and as for equation (1), the risk deduction $\triangle X$ (the second term in the curly brackets) is expressed as a fraction of $E[X]$.

A similar approach was taken by Scandizzo (1980), also exploiting the popular constant relative risk aversion function $U=(1/(1-A))Y^{1-A}$ in his attempt to synthesise risk accounting into the Squire and van der Tak (1975) framework of accounting for distributional impacts of projects.[1] Somewhat more diverse methods (including the constant absolute risk aversion function) and more complex intertemporal models were used by Wilson (1977) in analogous developments without focus on distributional aspects.

The approach of approximating certainty-equivalent project return through truncating Taylor-series expansions of expressions for expected utility, exploited by Little and Mirrlees (1974) for two special cases, is deserving of some closer attention. A general second-order approximation with approximately constant relative risk aversion was used for the 'large risky project' case (equation 1), and a first-order approximation with constant-relative-risk-aversion utility $U=(1/(1-A))Y^{1-A}$ was used for the 'mutually dependent' case (equation 2). This latter case thus ignores the second-order term involving the variance of project return modified by the size of project (relative to national income) effect. The logical way to accommodate this consideration would be to extend the approximation to include the second-order term as well as retaining the

[1] I am grateful to an anonymous referee for identifying parallels between risk adjustment in public projects and the valuation of risky assets in private financial markets through the capital asset pricing model (Sharpe 1964, Lintner 1965) and its recent extensions (e.g. Breeden 1979, Grossman and Sheller 1982, Makowski 1983). When empirically validated, these models may yield market-based estimates of risk adjustments that can be contrasted to the adjustments discussed herein for public projects.

jointly distributed income Y and project contribution X. Thus, Little and Mirrlees equation 4 (1974, p. 329):

$$(3) \qquad E[U'(Y)(X-\hat{X})] + (1/2)E[U''(Y)(X-\hat{X})^2 + \ldots = 0,$$

would be solved for the certainty equivalent $\hat{X}$.

Ignoring terms beyond those up to second-order (i.e. using only those written out in (3)) leads to solution of:

$$(4) \qquad E[U'(Y)X] - E[U'(Y)]\hat{X} + 0.5E[U''(Y)X^2] - E[U''(Y)X]\hat{X} + 0.5E(U''[Y)]\hat{X}^2 = 0,$$

which is quadratic in $\hat{X}$, namely:

$$(5) \qquad \hat{X} = \{E[U'(Y)] + E[U''(Y)X] \pm D^{0.5}\}/E[U''(Y)],$$

where

$$(6) \qquad D = \{E[U'(Y)] + E[U''(Y)X]\}^2 - 2E[U''(Y)]\{E[U''(Y)]E[U'(Y)] + 0.5E[U''(Y)X^2]\}.$$

Even with the simplest assumption about $U(Y)$, namely $A=1$ and $U(Y)=\ln(Y)$, the evaluation of equation (5) is awkward because the functions are rather more complex than the simple ones amenable to analytical treatment (Anderson and Doran 1978). Resort to Monte Carlo methods thus seemed mandatory to seek simple methods of evaluating approximate certainty equivalents in the 'large dependent project' case.

A Monte Carlo Study of Proportional Risk Deductions

A small experiment was designed to provide a basis for estimation. Two simplifying assumptions constitute the structure of the economy, namely the national income Y and project return X are bivariate normal (with simple correlation ρ and respective means and standard deviations μ_y, σ_y, μ_X, σ_X) and the utility function for total income has constant relative risk aversion (coefficient A), $U(Y+X) = (1/(1-A))(Y+X)^{1-A}$, or if $A=1$, $U(Y+X) = \ln(Y+X)$.

The experimental design was a complete factorial in four factors, at the following levels:

$$A = (0.1, 0.5, 0.9, 1, 2, 3),$$
$$R = \mu_X/\mu_Y = (0.01,\ 0.1,\ 0.25),$$
$$c_x = \sigma_X/\mu_X = (0.1,\ 0.5,\ 1),$$
$$\rho = (-1,\ -0.5,\ 0,\ 0.5,\ 1),$$

making a total of $6 \times 3 \times 3 \times 5 = 270$ treatments. The rationale for this design was to work in terms of variables that were as free of dimensions as possible and to span regions of the dimensionless variables that seemed of greatest relevance in applied project analysis. The speculated values for A were discussed above in the second section. A value of $R=0.01$ was felt to be suitably 'small' as a cutoff in considering 'large' projects (i.e. a 'large' project has a mean return greater than one per cent of mean national income). The upper level of R was even more arbitrarily set on the basis that it is difficult to imagine projects being much larger than providing about 25 per cent of national income (compare, for example, with the large mining projects in Papua New Guinea). Analogous considerations led to the range of values selected for the relative riskiness measured by c_X. As for R, the lower range choice was vindicated by the results in that projects 'less risky' than a coefficient of variation of 10 per cent have an insignificant risk deduction. Data on project risks are regrettably sparse, so the choice of the maximal value of $c_X = 1$ was merely that this seemed like a very high level indeed. The range for ρ was the entire feasible region from perfect negative to perfect positive correlation. Large positive correlations (but surely < 1) might apply, for instance, when a new project is being considered to extend production of a product already very important in the economy (e.g. sugar in Mauritius). Large negative correlations (but surely > -1) might apply for, say, flood control measures in Bangladesh. Such considerations lead to the design encompassing the two special cases discussed in the previous section.

National income was arbitrarily scaled at $\mu_Y = 1000$, $\sigma_Y = 10$ so that $c_y = 10/1000 = 0.01$ which is approximately the experience of the Australian rural sector in recent decades (Anderson 1979). While the mean level is clearly an arbitrary choice of no consequence, for results reported in proportional terms and experimental variables expressed in their dimensionless form, the setting of c_Y is not so arbitrary, as can be seen from equation (2). More variable incomes would impart greater economic significance to both c_X and ρ in comparable experiments. Linking the present experiment to the relatively volatile Australian experience seemed reasonable as a 'representative' level of variability faced by agrarian developing countries. A pseudorandom sample of 500 replications of X, Y and the derived variables was taken for each treatment and performance was measured as the proportional risk deduction P defined as:

$$P = \{E[Y+X] - (Y \hat{+} X)\}/E[X], \tag{7}$$

where certainty equivalent $(Y \hat{+} X)$ was found by inverting the utility function evaluated at sampled mean utility.

The most dramatic feature of the results was the general unimportance of correlation, particularly when any of A, R or c_X are 'small'. Most strikingly, very few *negative* risk deductions were found, and then only when $\rho = -1$ and the absolute values of these few cases were all very small (< 0.00005). The magnitudes of P were generally only 'significant' (> 0.01) when $A > 0.1$ and $R > 0.01$ and $c_X > 0.1$. The largest value of P computed was 0.388, of course, at the extreme point of the experimental design, namely $A = 3$, $R = 0.25$, $c_x = 1$ and $\rho = 1$.

The tabulated results make for unexciting reading but a subset is reported in Table 1. It seems natural to seek a more concise form of summary that permits interpolation to intermediate cases. Accordingly, a regression model was formulated for this purpose in a style that parallels that used above to express the Little and Mirrlees (1974) approximations in equations (1) and (2). Doubtless, other specifications could lead to relationships of higher predictive power but hardly of the same easy interpretation and intuitive (i.e. here multiplicative) structure. As well as altering the specification, the experimental domain could also be varied with surely some differences in results. In the spirit of parsimony and simplification that pervades this note, only one domain was considered and only one equation is selected for reporting.

TABLE 1

A Subset of the Sampled Mean Proportional Risk Deductions[a]

R	C_x	ρ	P
0.01	0.1	−0.5	0.009
0.01	0.1	0	0.009
0.01	0.1	0.5	0.009
0.01	0.5	−0.5	0.008
0.01	0.5	0	0.012
0.01	0.5	0.5	0.016
0.01	1	−0.5	0.009
0.01	1	0	0.020
0.01	1	0.5	0.033
0.1	0.1	−0.5	0.001
0.1	0.1	0	0.002
0.1	0.1	0.5	0.002
0.1	0.5	−0.5	0.019
0.1	0.5	0	0.026
0.1	0.5	0.5	0.029
0.1	1	−0.5	0.090
0.1	1	0	0.096
0.1	1	0.5	0.109

[a] $A = 2 \quad \mu_Y = 1000 \quad \sigma_Y = 10$

The selected equation estimated by ordinary least squares regression of the logarithms of the experimental data is:

(8) $$P = 0.0092\, A^{0.97(0.15)}(2+\rho)^{3.18(0.42)} c_X{}^{1.40(0.17)} R^{0.43(0.12)},$$

where standard errors are reported in parentheses and the adjusted $R^2 = 0.39$. With due regard to the precision of the equation and the approximating purpose to which it might be put, it is tempting to 'round off' the estimated coefficients to numbers that are easily computed on a calculator that does not have logarithmic or exponential functions, but does have a square root function, as in:

(9) $$P = 0.01\, A(2+\rho)^3 (c_X{}^3)^{0.5} R^{0.5}.$$

For further appreciation of the equations, and the data on which they are based, consider the case of an independent ($\rho = 0$), risky ($c_X = 0.5$) project and unit relative risk aversion ($A = 1$). Some comparisons with the equation (1) Taylor-series approximation are made in Table 2.

All the data of Table 2 are, in some sense, approximations. The simulated mean values are, however, at least very accurate estimates of the mean deductions relevant to the particular situation examined. Taking these as the true values against which the others may be contrasted, it can be seen that Little and Mirrlees' equation (1) underpredicts at low values of the relative project size whereas the regression equations underpredict most seriously at high values. Equation (8) predicts more reliably than the 'rounded off' equation (9). Overall, approximate results are indeed only approximate, but the precision is encouragingly high for all the equations at the 'middle' relative size of $R = 0.1$, although there are very few projects as large as this in reality.

TABLE 2

Some Proportional Risk Deductions P

Relative size of project R	Prediction from equation (1)	Simulated data sample mean	Predictions from equations (8)	(9)
0.01	0.001	0.006	0.004	0.003
0.1	0.0125	0.012	0.012	0.009
0.25	0.031	0.029	0.017	0.014

The summary equations can be rearranged to determine explicitly critical values for key variables contingent on given values for others. For example, the question might be posed, How large (relative to national income) must projects be to warrant some concern for risk accounting? More specifically, for purposes of illustration, if 'concern' is indicated by, say, $P \geq 0.002$, and if $A = 2$, $\rho = 0$ and c_x ranges over 0.1, 0.2, 0.3, the critical values for R, from equation (8) are 0.065, 0.007 and 0.002, respectively. The riskier the project, naturally, the smaller it needs to be to warrant attention to risk analysis.

Computing Risk Deductions in Practice

The state of the art of project appraisal is such that appropriate accounting for uncertainty continues to be a highly subjective matter. Comprehensive accounting must rely at least on detailed description of perceived uncertainties. These descriptions might be incorporated as (subjective) probability distributions in stochastic simulation models of projects (Reutlinger 1970) with, ideally, linkages to the macro economy. Social risk aversion could (and should) be embedded directly in such models.

Between such models and the most commonly used deterministic models of benefit-cost appraisal there are many possibilities, intermediate in terms of comprehensiveness and formality, in which approximate risk deductions could be exploited. It can be presumed that, whatever or whoever, an estimate of expected net present value, $E[PV]$, will be made. At least three additional pieces of information are required to compute a risk adjustment, namely:

(a) the ratio of $E[PV]$ to the expected present value of national income over the expected life of the project (analogous to R above);

(b) the simple correlation (ρ) between project return and national income; and

(c) the coefficient of variation of project present value (analogous to c_x above).

Such seemingly innocuous data may, however, be quite difficult to produce.

The first is quite easy, and may also be approximated (probably quite well) by choosing a 'representative' early year in which the project is fully on stream and taking R as the ratio of mean project return to mean national income for that year.

Subjective elicitation seems the most straightforward approach to determining the second item of data, the correlation coefficient, although such elicitation is never easy (Anderson, Dillon and Hardaker 1977, Ch. 2). Historical correlations between past national income and return from similar projects may be of some assistance in elicitation if it is judged that the past is a good guide to the future.

The third item of data is definitely the most challenging in the absence of a stochastic simulation model of the project (Anderson 1974). Purely subjective elicitation of the standard deviation or coefficient of variation of present value may be a possibility, but will surely be demanding of skill and patience. Perhaps the above suggestion of a representative year may offer a pragmatic 'middle course'. For such a period, an analyst may proceed most expeditiously (e.g. Anderson 1976) by assessing the mean and standard deviation of all the major uncertain variables (such as prices and quantities) and combining these into a coefficient of variation of return for the period. This number may then be taken as an approximation of the more relevant summary measure of variability. Such pragmatism is clearly imperfect, because intertemporal stochastic dependencies are ignored, as are the possibly significant uncertainties involved in the streaming of a project.

Once the data are assembled, substitution in equations (8) or (9) gives a proportional risk deduction P and, if this is judged to be 'significant' (say, >0.01), the previously estimated $E[PV]$, which may involve income distributional accounting, is multiplied by $1-P$. If the adjustment is judged to be insignificantly small, the analyst could conclude with fair confidence that, in this instance, uncertainty has no qualifying impact on appraisal and, accordingly, proceed to ignore it and take the project decision on the certainty appraisal.

Whether or not risk accounting in public project appraisal is important is largely an empirical question. It is a question that has very seldom been asked, and most analysts have merely presumed the unimportance of risk and proceeded to ignore it in public appraisal. This is not to suggest that aversion to risk is unimportant for private investors who, depending on their wealth and personal attitudes are probably routinely risk averse and, as well, must grapple with similar cautious attitudes of lending institutions.

The results presented do support such past presumptions of unimportance of risk, at least for countries like Australia where projects (including agricultural ones like major dams) tend to be 'small' relative to national income and, given the diversity of the economy, not highly correlated with national aggregates. The situation may, however, be rather different for large projects in small, relatively undiversified, economies.

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