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Agriculture and Rural Development
Department
The World Bank
November 1989
WPS 290

# Risk-Adjusted Rates of Return for Project Appraisal

Avinash Dixit and Amy Williamson

Risk premia vary greatly across countries and sectors — so adjusting for risk on an individual project's merits makes more sense than applying a general risk premium on calculations for all lending.

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Incorporating risk assessment into public project appraisal makes sense when project risk is significantly correlated with uncertainty about national income. It is especially important in countries that specialize in particular agricultural or resource sectors.

Calculating costs and returns is similar for real and financial investments — but the treatment of risk is better developed for financial investments. Dixit and Williamson present a pilot model — analogous to the capital asset pricing model — that relates the excess return required from a project to project risk.

Dixit and Williamson found that:

Risk corrections can be substantial. The size of the adjustment is affected by the coefficient of variation of GNP, the coefficient of variation for project return, and the correlation between GNP and project return.

The intuition that risk is great for further investment in a crop or sector that constitutes a large part of a country's GNP is not invalid, but this effect may be offset by other forces in operation.

Risk corrections can be negative because of a negative correlation between project return and GNP. Project risks with negative risk adjustments — such as projects involving rice in Nigeria and groundnut oil in Senegal — are especially attractive. It will be useful to know how to identify them.

Risk premia vary greatly across countries and sectors — so recognizing the risk correction needed for each project on its own merits makes more sense than including a common general risk premium in the rate of return required for all lending. The result would be a reallocation of lending among projects, not a stiffening of standards for all projects and therefore acceptance of fewer.

Risk corrections are small for many sectors and countries. Identifying risk in project appraisal will be simplified if a general class of country and sector combinations can be identified in which risk is negligible — so efforts can be concentrated on the other categories, where the proposed treatment of risk makes a big difference.

Risk affects investment projects in many different, subtle ways. One should not aim for a simple table of risk adjustment terms to be read in a manual and applied directly. Even when the procedure is refined, each situation will need economic analysis and oversight.

Resource requirements for this are not great, however. After routines are developed, one professional economist should be able to incorporate risk assessment into project analysis in less than a week.

This paper is a product of the Agricultural Policies Division, Agriculture and Rural Development Department. Copies are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Cicely Spooner, room N8-035, extension 30464 (39 pages with tables).

# Risk-Adjusted Rates of Return for Project Appraisal

by
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## Table of Contents

| | | |
|---|---|---|
| I. | A Brief Review of Current Theory and Practice | 2 |
| II. | The Basic CAPM Formula | 6 |
| III. | Adaptation for Project Appraisal | 8 |
| IV. | An Experimental Application | 14 |
| V. | Comments on the Results | 20 |
| VI. | Directions for Further Work | 23 |
| VII. | Some Suggestions for Project Design | 25 |
| | Technical Appendix | 28 |
| | Annexes | 33 |
| | References | 39 |

* We thank Whitney Newey of Princeton University and Diderik Lund of the University of Oslo for useful suggestions, Gene Grossman of Princeton University, and Jock Anderson of the World Bank for comments on a previous version, and Peter Hazell of the World Bank for discussions and advice.

## I. A BRIEF REVIEW OF CURRENT THEORY AND PRACTICE

No one would deny that uncertainty is an important feature of most investment projects. There is much less agreement, however, as to the appropriate methods for dealing with it at the stage of project appraisal. There are controversies at the theoretical level, and largely neglect at the practical level. The history of both of these facets is very ably described in an earlier World Bank document by Anderson (1983, revised in 1989), and it would be pointless for us to repeat it. Our purpose in this report is to explore the possibility of improving upon current practice by using some simple theory.

Two disclaimers should be emphasized at the outset. Our aim is not that of perfecting the theory. On the contrary, we accept many approximations without apology in the interests of practicality. Nor do we aim to lay down an ideal practical procedure; on the contrary, we seek only a way of doing better than nothing. If this exploratory exercise is thought to hold promise, additional work to improve both the theory and its empirical implementation will be needed.

The basic idea is to exploit the conceptual and analytical link between real and financial investments. Both involve similar calculations of costs and returns. But the treatment of risk is much better developed for financial investments. The capital asset pricing model, with its beta coefficients, has not only succeeded in treating issues that project evaluation has long ignored, but also has done this in a way that can be used in practice, and is indeed widely used. Of course, the capital asset pricing model cannot be transferred directly or straightforwardly to the context of projects in developing countries; substantial modifications are needed to take into account the limitations of capital markets in these countries. But we believe that the task is manageable and that it results in worthwhile improvements on current practice. This paper is a first step in that direction.

According to Anderson, the Bank's prevailing practice in project evaluation "has been confined mostly to the certainty model." The certainty model is simply using "expected values ... for all truly random elements," with a few ad hoc corrections to take into account non-linearities that will affect the expectation of the present value. Thus no allowance is made for risk aversion.

Projects are deemed acceptable if their expected present value calculated at the specified discount rate is positive, or if their expected rate of return exceeds the specified target rate. The specified rates are usually around ten percent per year in real terms. This is quite a high figure, given that the riskless real rates of interest rarely exceed two to three percent. The reason for using such a high rate is not very clear, but presumably it reflects some generalized allowance for risk, common to all projects, as well as the greater opportunity cost of capital in developing countries. A more explicit treatment of risk would not mean adding a risk premium on top of the high general rate currently used. It would mean using an appropriately lower riskless base rate to which the risk premia are added. The aim is to recognize the risk correction needed for each project on its own merits. The result would be a reallocation of lending among projects taking into account their individual risk effects, not a stiffening of the standards for all projects and therefore acceptance of fewer.

Theoretical justification for the current practice, when any is offered at all, consists of an appeal to the Arrow-Lind theorem. This says that risk aversion can be ignored when evaluating a public investment project if (i) the project is small in relation to the national product, and (ii) the risk in the project return is uncorrelated with that of the national product.

The assumptions are not innocuous. The first is violated for some major power, transport and irrigation projects. These are not the focus of our study; the implications of risk for such large projects are being examined by other units in the Bank. [1] The second assumption is violated in many circumstances, especially for countries with significant specialization in a crop or raw material whose price fluctuates on world markets. When a new investment project in the same sector is being considered, its return will be perfectly correlated with the return to all previous investments in that sector, and therefore significantly positively correlated with national income or wealth as whole. In other words, such a project carries a significant systematic or undiversifiable risk, and considerations of risk aversion become important.

The capital asset pricing model (CAPM) handles exactly this

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1/ See a draft report entitled "Preliminary Stage of a Research Program on Improved Methodology for Incorporating Risk and Uncertainty in Power System Planning: Literature Review and Survey of Current Practices," prepared for the World Bank by Information for Investment Decisions, Inc., nd.

situation for financial assets. Its main conclusion is that the risk premium for a particular asset is governed not by the absolute size of its risk (measured, for practical convenience, by the standard deviation of the return), but by the systematic or undiversifiable component of risk (the covariance between the return to this asset and the return to the whole market portfolio). In financial economics, the relevant effect is captured in the beta coefficient of the asset. Our proposal is to calculate the equivalent of beta coefficients for real investment projects. The task is harder because many countries where the Bank is engaged in project lending do not have well-developed financial markets that will allow a ready calculation of betas. The model must be reformulated to yield an operational formula that performs the same function as the beta formula of CAPM. In other words, where the CAPM can use an observable market price of risk, we must develop the formula in terms of a shadow price of risk, the magnitude of which must be estimated indirectly or allowed to vary over a plausible range.

This proposal is not new. The idea was presented in the earliest manuals of project appraisal, namely Little and Mirrlees (1974) and UNIDO (1972). But their focus was on market imperfections that gave rise to a difference between the market wage and the shadow price of labor, and likewise between the market interest rate and the shadow or accounting rate appropriate for evaluation of public projects. They regarded the case of correlated risk as exceptional, but did not provide evidence to support this belief. An important part of our aim is to determine just how important the issue is.

In the same way, Anderson (1983) performed some simulations that led him to conclude that risk premia were generally negligible. In that work, he maintained an assumption that the coefficient of variation of GNP was one percent, whereas a substantially larger value is appropriate for many natural resource dependent economies. In more recent work (Anderson, 1989), he has relaxed this assumption and finds that risk premia are "still quite small." But some of his cases produced quite significant risk premia of two percentage points for the required rate of return. More importantly, the issue cannot be settled by such simulations in the abstract. A test based on real data is needed.

In the next section, we give a brief review of the CAPM formula for the risk premium. In Section III we discuss the modifications that are necessary when adapting the method to project evaluation in developing countries and state the formula we use. The derivation is in the Appendix. In Section IV we apply the result to calculate the risk premia for sample projects representing several sectors and countries. The remaining sections comment on various aspects of the results and suggest ways to proceed further.

## II. THE BASIC CAPM FORMULA

The capital asset pricing model (CAPM) establishes a formula for the expected rate of return to an asset. [2] Let $r_i$ be the random rate of return on asset $i$, and let $\eta_i$ be its mean and $\delta_i$ its standard deviation. Let $\rho_{im}$ be the correlation coefficient between $r_i$ and the

2/ See any textbook on financial economics, e.g., Garbade (1982).

random rate of return on the whole market portfolio, $r_m$. Let $r_o$ be the riskless rate of return. Then

$$\mu_i - r_o = \pi \rho_{im} \sigma_i, \tag{1}$$

where $\pi$ is the same for all assets and is interpreted as the market price of risk. The factors multiplying $\pi$ comprise the systematic or undiversifiable risk of this asset. This depends not merely on the standard deviation of the asset return, but on the extent to which the asset's particular risk is correlated with that of the market as a whole.

If we think of the whole market portfolio as an asset m, then of course $\rho_{mm}=1$, and the expected rate of return on the market satisfies

$$\mu_m - r_o = \pi \sigma_m. \tag{2}$$

Dividing (1) by (2), we can write the basic equation of CAPM:

$$\mu_i - r_o = \beta_i(\mu_m - r_o), \tag{3}$$

where the beta coefficient is defined by

$$\beta_i = \rho_{im}\sigma_i/\sigma_m. \tag{4}$$

The betas for particular stocks can be estimated by running time series regresssions based on equation (3). The market price of risk can be inferred by observing the rest of the magnitudes that appear in (2). It is possible to allow time-varying betas, and even special "news events" that cause one-time shifts in asset prices and returns.

## III. ADAPTATION FOR PROJECT APPRAISAL

This method can be applied to the appraisal of risky investment projects in developing countries. We can in principle think of each project as an asset. Then the expression on the right hand side of (1) or (3) is the risk-adjustment we should make when evaluating the project. That is, the project is justified only if it is expected to have a rate of return that exceeds the rate of return on a riskless investment by this much. But this procedure cannot be carried out without substantial modifications.

The problem is that important assumptions about well-functioning risk markets underlie the CAPM, and in most developing countries such markets are incomplete or non-existent. Therefore the CAPM must be reformulated for our purpose. Information contained in the market price of risk $\pi$, or the expected rate of return on the market portfolio, $\mu_m$, cannot be obtained by mere observation of market behavior. We must formulate the model differently.

The CAPM formula is derived by considering the portfolio choice problem of a representative well-diversified consumer. We replace this by an approach that is the natural one in the context of social cost-benefit analysis, namely one based on the optimization of a social welfare function. Each individual has a limited menu of risky assets; the government has its own choice among public projects. It also has tax and price instruments to influence individual choices. The market price of risk is then replaced by a shadow social value of risk that emerges from the government's optimization problem. The result will depend on the individual attitudes to risk, the allocation of risk across individuals, and the range of choices that is available to the economy as a whole. The theory is not original; some of the numerous predecessors were mentioned the introduction.[3] Our contribution is developing the method to a point at which practical implementation can be contemplated.

In this exploratory exercise, we have neglected the question of the distribution of risk across individuals in the economy. Thus we regard the social welfare problem as that of maximizing the expected utility of a representative individual. While this is a serious limitation, it conforms to the practice of project appraisal even without the consideration of risk. As we understand it, the reality of social cost-benefit analysis in the Bank does not include an integrated treatment of efficiency and equity aspects as would be dictated by the strict logic of the Diamond-Mirrlees theory. Rather, the numerical calculations of the rates of return or discounted present values deal with the aggregate or efficiency aspects alone; distributional considerations are brought in separately by listing the impacts the project would have on particular groups. In the same way, we focus on the economic efficiency aspects of risk in our basic formula, leaving the distributional aspects to be considered separately. Of course, we hope that better integrated treatments of aggregates and distribution

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3/ More detailed recent theoretical treatments can be found in Scandizzo, Hazell and Anderson (1984) and Lund (1988).

will emerge eventually, whether or not risk is treated explicitly.

Even when a country is treated as a representative individual, there is the question of the range of assets over which this individual can diversify. With free international capital mobility, this can, in principle, comprise the whole world's asset portfolio. Thus a developing country dependent on a particular natural resource with a risky world price can, in principle, sell shares in this risky asset on the world capital market and diversify its own portfolio by holding claims on other countries' assets with imperfectly correlated risks. But in practice, and especially for developing countries, such international diversification is very limited. Governments restrict capital movements across their borders for a mixture of good and bad reasons; even without restrictions, sovereign risk and moral hazard would limit international equity holdings. Therefore, it has become common to think of each country's portfolio as comprised of title to its own resource stocks and output flows. We too make this assumption, but wish to point out that, in specific contexts, it may be necessary to allow a wider menu of assets for the country's portfolio.

Finally, we use the simplest static (really two-period) CAPM. This requires careful interpretation. First, the periods aggregate, respectively, the investment phase and the payoff phase. Each of these generally lasts more than one calendar year, and there is often a considerable gestation lag between the two. At the time the project is evaluated we are forecasting the payoffs at a future time that may be some years away. The error variance of the forecast should reflect this. Second, the mathematical formula derived in the Technical Appendix involves the coefficient of variation and the correlation coefficient for second-period consumption, not GNP. In a strict two-period interpretation, all of GNP is consumed in the second period, so there is no difference between the two. For this initial exploration, that is the approach we take. In practice the world does not end when the payoff from this project ends. If the project lasts for only a short time, consumption may differ a lot from income; in particular it will be the outcome of an intertemporal smoothing decision and therefore a lot less variable. The difference becomes less pronounced as the project life becomes longer. If our simple approach is thought to show promise, a more elaborate model can be constructed by analogy with the intertemporal capital asset pricing model (ICAPM).

We model project uncertainty by two multiplicative shocks, one for the world price of the output, and the other for the country- and sector-specific productivity. It is also important to consider real exchange rate variations, which affect the country's economic welfare via not only the national income but also the consumer price index.

The mathematics of the model is in the Technical Appendix; here we summarize the result. The four random variables in the problem - the real exchange rate e, the price shock p, the productivity or quantity shock q, and the national income $Y_2$ - are assumed to be jointly lognormally distributed:

$$(\ln(e), \ln(p), \ln(q), \ln(Y_2)) \sim N(\nu,\Sigma), \tag{5}$$

where $\nu$ is the four-dimensional vector of means, and $\Sigma$ is the four-by-four positive definite variance-covariance matrix. Let $\mu$ denote the expected rate of return on the project, and $r_o$ the riskless rate. Then the formula for the difference between these two (the risk adjustment) is, where $\rho$ is the coefficient of relative risk aversion and $\alpha$ is the share of traded goods in total consumption,

$$\mu - r_o = \rho[\sigma_{14}+\sigma_{24}+\sigma_{34}] - \alpha(\rho-1)[\sigma_{11}+\sigma_{12}+\sigma_{13}]. \tag{6}$$

This looks more complicated than the CAPM formula (1), but that is mainly because of the exchange rate risk which affects utility in two ways. To bring out the underlying analogy, suppose the real exchange rate is non-random such that all the entries in the first row and column of the variance-covariance matrix $\Sigma$ are zero. Then the right hand side (6) reduces to

$$\rho[\sigma_{24} + \sigma_{34}]. \tag{7}$$

The total shock to the project value is pq, so $[\sigma_{24} + \sigma_{34}]$ is the covariance between the logarithms of the project shock and $Y_2$. Further, the standard deviation of the logarithm of a lognormal variable is approximately the coefficient of variation of the variable itself. Suppose $\ln(x)$ is $N(\mu, \sigma^2)$, so the standard deviation of $\ln(x)$ is $\sigma$. Then, as in Aitchison and Brown (1957, p.8),

$$E(x) = \exp(\mu + \sigma^2/2),$$

and

$$\mathrm{Var}(x) = \exp(2\mu + \sigma^2)[\exp(\sigma^2) - 1].$$

Therefore, $\sigma'$, the coefficient of variation of x, is

$$\sigma' = [\mathrm{Var}(x)]^{1/2}/E(x)$$
$$= [\exp(\sigma^2) - 1]^{1/2},$$

which, by expansion of $\exp(\sigma^2)$, is

$$\sigma' = \sigma(1 + \sigma^2/2 + \sigma^4/6 + \ldots)^{1/2}.$$

Thus $\sigma'$ is a good approximation of $\sigma$ when $\sigma << 1$. For example, for $\sigma = 0.2$, the ratio of the two is 1.010; for $\sigma = 0.4$, it is 1.041.

Using this appoximation, we can write the risk adjustment formula (7) as

Excess of expected project return over riskless rate
= Coefficient of relative risk aversion
x Coefficient of variation of GNP
x Correlation between project shock and GNP
x Coefficient of variation of project shock.

The analogy with the CAPM formula (1) in the text is almost exact. Since the random variables in (1) were rates of return (which are already scaled) while those in the above expressions are levels of the technology shock and GNP (which are unscaled), it is natural that the coefficients of variation should replace standard deviations.

The product of the coefficients of relative risk aversion and variation of GNP is the shadow price of risk, replacing the market price of CAPM. The new problem is that the society's coefficient of relative risk aversion is not observable. In fact, being a property of the social preference function, it is inherently imprecise and subject to debate. We could get some idea of its magnitude by observing the risk-return tradeoffs revealed by past decisions. Values of $\rho$ between one and two are often thought to be reasonable. In specific applications the judgement may be different. But we claim that the formulation serves a useful function by focusing the debate on a relatively simple parameter.

## IV. AN EXPERIMENTAL APPLICATION

The CAPM model has been used quite successfully in financial economics. Therefore the analogy offers some hope for the approach sketched out in the previous section. But an exploratory exercise is needed to get a better idea of the potential and limitations of the method. By trying it out in a simple form on real data, we can see if it generates numbers that are of sensible order of magnitude. The exercise also indicates the points where the theory and the data need improvement. In this section we report the results from such an attempt. At various places, and in the next section, we draw inferences that should guide future work along these lines.

We consider some simple hypothetical projects, the output of each consisting of a single tradeable commodity. For each such project in each country considered, we forecast the magnitudes needed in (6) over the average future period when the payoff from this project will accrue. For illustrative purposes, we have chosen this to be five years from the time the investment is made. The risk aversion parameter $\rho$ must be fixed exogenously as explained above, and we show the results for two alternative values, $\rho = 1$ and 2.

The data needed to implement the method consist of time series of the world prices of a group of commodities and the real exchange rates, commodity outputs, and GNP for a large group of countries. The maximum period covered was 1961-87; for some countries a smaller period had to be used. World price data were obtained from the World Bank's International Economics Department, International Commodity Markets Division, and are the international prices of standard types of commodities in major markets (see Annex 1 for specific sources and definitions). These prices are deflated to 1980 U.S. dollar values with the IMF's "World Consumer Price Index", a GDP-weighted average of country consumer price indices.

We use a simple GDP-deflator-weighted real exchange rate. The real local currency per U.S. dollar rate is defined as the nominal local currency per U.S. dollar rate multiplied by the ratio of the U.S. GDP deflator to the national GDP deflator. The price indices, deflators and the nominal exchange rates were obtained from the IMF's International Financial Statistics Yearbook. The GDP deflator is not available for all countries over the entire period 1961-87. This would have forced the exclusion of a few countries (Burkina Faso, Cameroon, Cote D'Ivoire, Niger, Senegal, Sudan and Bangladesh) from the analysis. In those cases we have used the consumer price index (for both the country and the United States) to construct real exchange rate series. As well, we have used the rate of change of the CPI to lengthen the GDP deflator series for Uganda. We tested this procedure by comparing the results using the GDP deflator and the CPI deflator for some other countries where both were available and found the differences to be small.

The source of commodity output data for the individual countries is the FAO Production Yearbook. By country, each commodity is classified as "staple" (s), "export" (x)[4] or "metal or mineral" (mm). Because multiple data sources are used, there are some differences in commodity definitions (see Annex 1) which could not be avoided. The GNP series were obtained from the World Bank's National Accounts database and are valued at market prices in constant local currency (1980 values).

We assume that each time series ($x_t$) (in logarithms) has an autoregressive structure,

$$x_t = \alpha + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \beta_3 x_{t-3} + \epsilon_t, \tag{8}$$

where the $\epsilon_t$ are white noise with variance $\sigma^2$. In each case a regression was estimated, and the residuals were captured to become the data in the

4/ An "export" is defined as a crop for which the average export value over the period in question is greater than or equal to 2 percent of total agricultural export value; a "staple" is simply a crop which is produced in excess of 100,000 metric tons per year but does not meet the export criterion.

calculation of error variances and covariances.[5]

Suppose the decision date is t, and we know the values of $x_t$, $x_{t-1}$, etc. We want to forecast the mean and the variance s periods into the future, that is, for $x_{t+s}$, conditional on this information.[6] To do so, we use the lag operator L to write (8) as

$$\{1 - \beta_1 L - \beta_2 L^2 - \beta_3 L^3\} x_t = \alpha + \epsilon_t.$$

Assume a solution

$$x_t = \{1 + \psi_1 L + \psi_2 L^2 + \ldots\}(\alpha + \epsilon_t). \tag{9}$$

Then the coefficients $(\psi_j)$ can be obtained from the identity

$$\{1 - \beta_1 L - \beta_2 L^2 - \beta_3 L^3\}\{1 + \psi_1 L + \psi_2 L^2 + \ldots\} \equiv 1.$$

Carrying out this exercise gives

$$\psi_1 = \beta_1,$$

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5/ Where evidence of significant positive serial correlation in the residuals was found, a similar equation was used for the differences $x_t^* = x_t - \eta x_{t-1}$, and subsequent formulas for forecast error variances etc. were modified appropriately. No significant evidence of heteroscedasticity was found.

6/ See any textbooks on time series, e.g., Box and Jenkins (1976).

$$\psi_2 = \psi_1\beta_1 + \beta_2,$$

$$\psi_3 = \psi_2\beta_1 + \psi_1\beta_2 + \beta_3,$$

and for $j \geq 4$ we have the recursive formula

$$\psi_j = \psi_{j-1}\beta_1 + \psi_{j-2}\beta_2 + \psi_{j-3}\beta_3.$$

These properties are important in deriving forecast error variances. We are trying to forecast $x_{t+s}$ at time t. Using (9), and ignoring $\alpha$ which makes no difference for the present purpose, we have

$$x_{t+s} = \epsilon_{t+s} + \psi_1\epsilon_{t+s-1} + \ldots + \psi_s\epsilon_t + \ldots$$

At time t we know $x_t$, $x_{t-1}$ etc., and, therefore, implicitly $\epsilon_t$, $\epsilon_{t-1}$ etc. The forecast error variance s periods ahead is then

$$V(s) = [1 + \psi_1^2 + \psi_2^2 + \ldots + \psi_{s-1}^2]\sigma^2. \quad (10)$$

Define the coefficient of $\sigma^2$ in (10) as the <u>multi-year forecast error variance multiplier</u>

$$M(s) = 1 + \psi_1^2 + \psi_2^2 + \ldots + \psi_{s-1}^2. \quad (11)$$

We use this for s=5. Note that each time series has its own coefficient $\psi_j$ computed using its own regression (8).

The same principle can be used to find the covariances in equation (6). We can estimate one-period covariances for any two time series using their residuals. Let $\Sigma(1)$ denote this one-period variance-covariance matrix, and $\Sigma(5)$ that for forecasts five periods ahead. Let $M_j(5)$ be the five-year forecast error variance multiplier for series j. Hence

$$\sigma_{ij}(5) = \sigma_{ij}(1)\left[M_i(5)M_j(5)\right]^{1/2}. \tag{11}$$

These are the values are used in the risk adjustment formula (6).

For the time series that required a further adjustment for serial correlation of the residuals (see footnote 4), the lag operator equation (9) becomes

$$(1 - \eta L)(1 - \beta_1 L - \beta_2 L^2 - \beta_3 L^3)x_t = u_t,$$

and solution by the method of undetermined coefficients proceeds as before, yielding

$$\psi_1 = \beta_1 + \eta,$$
$$\psi_2 = \psi_1(\beta_1 + \eta) - (\beta_2 - \eta\beta_1),$$

and so on.

The results for a number of countries and projects for the production of a number of commodities are shown in Tables 1 and 2. The first classifies the results by country, and the second by commodity. The countries and the commodities were chosen from a larger data set so as to present a mixture of cash crops, staples and minerals, as well as a mixture of cases where the commodity is a large or small part of a country's economy. The tables present the results for two assumed values of the relative risk aversion parameter, $\rho = 1$ and 2, and for the cases of multiplicative shocks to the world price, output quantity (interpreted as a country- and commodity-specific productivity shock) and the two together (value or project shock). Annex 2 lists some of the components that contribute to the results in Tables 1 and 2. As explained above, the coefficient of variation of a variable is estimated by the standard deviation of the logarithm of the variable. The second, third and fourth columns (CV of GNP, correlation between project shock and GNP, and CV of project shock) correspond to the risk adjustment (7) in which the real exchange rate is non-random.

Once again we should emphasize that Tables 1 and 2 contain the preliminary results of an exploratory exercise. They are meant to be an input into further thinking, not into immediate use in assessing actual projects. In the following sections, we offer some observations on these results, attempt to derive some preliminary insights from them, and suggest directions for future work.

## V. COMMENTS ON THE RESULTS

The first point to note is that risk corrections can be substantial. The CAPM viewpoint suggests three important determinants of the size of the adjustment: the coefficient of variation of GNP, the coefficient of variation for the project uncertainty, and the correlation

TABLE 1: RISK ADJUSTMENTS BY COUNTRY (%)

| Country/ Commodity | Period/ Type | Coefficient of Relative Risk Aversion (p) = 1 | | | Coefficient of Relative Risk Aversion (p) = 2 | | |
|---|---|---|---|---|---|---|---|
| | | World Price | Quantity | Output Value | World Price | Quantity | Output Value |
| BURKINA FASO | 1964-87 | | | | | | |
| cotton | x | 0.02 | 1.07 | 0.99 | -0.74 | 1.58 | 1.55 |
| sorghum | s | -0.18 | 0.31 | 0.02 | -0.67 | -0.25 | -0.21 |
| CAMEROON | 1965-87 | | | | | | |
| bananas | x | 3.12 | 1.45 | 2.14 | 5.63 | 2.31 | 3.85 |
| cocoa | x | 5.88 | 9.99 | 13.44 | 10.77 | 19.17 | 25.85 |
| coffee | x | 5.00 | 2.36 | 4.93 | 9.19 | 3.97 | 9.07 |
| cotton | x | 0.07 | 6.06 | 3.70 | -0.57 | 11.18 | 6.52 |
| rubber | x | 6.00 | -0.25 | 3.33 | 11.45 | -1.02 | 6.34 |
| maize | s | 6.88 | 2.24 | 6.69 | 12.87 | 3.71 | 12.49 |
| COTE D'IVOIRE | 1964-87 | | | | | | |
| bananas | x | 0.27 | 0.06 | 0.45 | -0.24 | -1.11 | 0.00 |
| cocoa | x | -0.53 | -0.12 | -0.53 | -2.11 | -1.37 | -2.13 |
| coffee | x | -0.31 | 0.77 | 0.58 | -1.48 | 0.75 | 0.62 |
| cotton | x | -0.03 | -0.25 | -0.16 | -1.34 | -1.51 | -1.50 |
| palm oil | x | -0.97 | 1.07 | 0.23 | -3.71 | 1.12 | -1.24 |
| rubber | x | 0.29 | 0.21 | 0.68 | -0.08 | -0.54 | 0.73 |
| maize | s | 0.21 | -0.16 | 0.17 | -0.82 | -1.78 | -1.25 |
| rice | s | 0.05 | -0.23 | -0.06 | -0.47 | -1.52 | -0.64 |
| ETHIOPIA | 1964-83 | | | | | | |
| coffee | x | 0.05 | -0.09 | 0.03 | 0.31 | -0.40 | 0.28 |
| beef | s | -0.09 | -0.05 | -0.07 | -0.15 | -0.27 | -0.05 |
| maize | s | -0.06 | -0.08 | -0.07 | -0.14 | -0.51 | -0.28 |
| sorghum | s | -0.05 | -0.11 | -0.09 | -0.14 | -0.62 | -0.39 |
| sugar | s | -0.28 | 0.06 | -0.15 | -0.70 | -0.12 | -0.44 |
| wheat | s | -0.24 | 0.04 | -0.12 | -0.42 | -0.09 | -0.13 |
| GHANA | 1964-87 | | | | | | |
| cocoa | x | 0.38 | 1.25 | 0.90 | -4.27 | -2.79 | -3.30 |
| maize | s | 1.20 | 1.69 | 2.17 | -2.95 | -2.26 | -1.46 |
| sorghum | s | 1.41 | 1.96 | 2.65 | -2.31 | -1.87 | -0.43 |
| bauxite | mm | 1.19 | 3.46 | 3.92 | -2.93 | 2.96 | 3.77 |
| KENYA | 1967-85 | | | | | | |
| coffee | x | -0.72 | 0.39 | -0.30 | -1.90 | 0.46 | -0.83 |
| tea | x | 0.00 | -0.01 | 0.02 | 0.20 | -0.62 | 0.20 |
| beef | s | 0.38 | 0.17 | 0.58 | 0.12 | -0.21 | 0.52 |
| maize | s | 0.89 | -0.23 | 0.70 | 1.74 | -1.26 | 1.10 |
| sorghum | s | 0.70 | -0.31 | 0.42 | 1.11 | 0.14 | 1.86 |
| sugar | s | 1.16 | -0.28 | 0.91 | 2.94 | -0.82 | 2.74 |
| MADAGASCAR | 1964-82 | | | | | | |
| beef | x | -1.69 | -1.69 | -1.74 | -3.78 | -3.77 | -3.78 |
| coffee | x | -1.40 | -1.26 | -1.02 | -3.31 | -2.87 | -2.41 |
| sugar | x | -1.06 | -1.49 | -0.91 | -2.34 | -4.14 | -2.72 |
| maize | s | -1.75 | -1.70 | -1.81 | -3.84 | -4.01 | -4.08 |
| rice | s | -2.10 | -1.51 | -1.97 | -4.53 | -3.56 | -4.33 |
| MALAWI | 1964-87 | | | | | | |
| cotton | x | 1.86 | -0.11 | 1.55 | 3.29 | -0.42 | 2.83 |
| maize | x | 0.56 | 0.74 | 1.10 | 0.67 | 1.10 | 1.74 |
| tea | x | 0.53 | 0.35 | 0.69 | 1.22 | 0.19 | 1.37 |
| tobacco | x | 1.00 | -0.59 | 0.22 | 1.82 | -1.33 | 0.45 |
| NIGER | 1966-87 | | | | | | |
| groundnut oil | x | -0.27 | 6.93 | 6.33 | -2.06 | 13.05 | 11.01 |
| sorghum | s | -1.09 | 2.13 | 0.71 | -2.87 | 3.61 | 0.75 |
| NIGERIA | 1964-85 | | | | | | |
| cocoa | x | 1.47 | -1.83 | 0.80 | 2.31 | -5.29 | 0.86 |
| palm oil | x | 1.04 | -1.07 | 1.14 | 2.08 | -3.61 | 2.31 |
| maize | s | 0.00 | -0.86 | 0.31 | -0.76 | -3.74 | -0.65 |
| rice | s | -3.01 | -3.80 | -5.63 | -6.37 | -9.05 | -11.58 |
| sorghum | s | -0.25 | -0.11 | 0.80 | -1.31 | -1.62 | 0.90 |
| crude petroleum | mm | 3.11 | 4.52 | 9.79 | 6.99 | 8.50 | 19.33 |

TABLE 1: RISK ADJUSTMENTS BY COUNTRY (%)

| Country/ Commodity | Period/ Type | Coefficient of Relative Risk Aversion (p) = 1 | | | Coefficient of Relative Risk Aversion (p) = 2 | | |
|---|---|---|---|---|---|---|---|
| | | World Price | Quantity | Output Value | World Price | Quantity | Output Value |
| RWANDA | 1969-87 | | | | | | |
| coffee | x | 0.75 | 0.36 | 0.94 | 0.85 | 0.14 | 1.20 |
| tea | x | -0.68 | 0.24 | -0.61 | -1.85 | 0.02 | -1.62 |
| sorghum | s | 0.07 | 0.29 | 0.19 | -0.22 | -0.09 | -0.10 |
| SENEGAL | 1970-87 | | | | | | |
| cotton | x | -0.84 | 0.50 | -0.58 | -3.31 | -1.04 | -3.47 |
| groundnut oil | x | -1.25 | 0.41 | -1.08 | -5.23 | -0.20 | -4.54 |
| rice | s | -2.15 | 0.02 | -2.30 | -4.88 | -1.41 | -5.40 |
| phosphate rock | mm | -0.61 | -0.23 | -1.08 | -3.42 | -1.86 | -4.40 |
| SUDAN | 1964-87 | | | | | | |
| cotton | x | -0.50 | -0.08 | -0.69 | -1.38 | -0.69 | -1.81 |
| sorghum | x | -2.34 | 0.98 | -1.46 | -5.25 | 1.46 | -3.54 |
| beef | s | -2.80 | 0.34 | -2.57 | -6.17 | 0.11 | -5.80 |
| sugar | s | 1.82 | -1.40 | 0.31 | 3.40 | -3.31 | 0.35 |
| TANZANIA | 1968-85 | | | | | | |
| coffee | x | 0.29 | -0.04 | 0.25 | 0.27 | -0.15 | 0.27 |
| cotton | x | 0.38 | 0.06 | 0.43 | 0.46 | -0.08 | 0.53 |
| tea | x | 0.02 | 0.10 | 0.12 | -0.25 | 0.09 | -0.01 |
| tobacco | x | 0.06 | 0.03 | 0.08 | 0.22 | -0.19 | 0.18 |
| maize | s | 0.02 | 0.37 | 0.38 | -0.10 | 0.48 | 0.52 |
| rice | s | 0.10 | 0.01 | 0.09 | 0.41 | -0.30 | 0.26 |
| sorghum | s | 0.00 | -0.02 | -0.03 | -0.08 | -0.02 | 0.04 |
| sugar | s | 0.03 | -0.03 | -0.02 | 0.16 | -0.28 | 0.03 |
| UGANDA | 1970-87 | | | | | | |
| coffee | x | 1.74 | 1.52 | 1.95 | 3.43 | 2.99 | 3.86 |
| cotton | s | 2.79 | 3.43 | 4.91 | 5.53 | 6.78 | 9.74 |
| maize | s | 1.94 | 2.18 | 2.81 | 3.83 | 4.30 | 5.56 |
| sorghum | s | 2.10 | 1.61 | 2.40 | 4.16 | 3.17 | 4.76 |
| sugar | s | 1.78 | 1.19 | 1.66 | 3.52 | 2.32 | 3.28 |
| ZAMBIA | 1964-86 | | | | | | |
| maize | s | -0.62 | 0.05 | -0.40 | -8.39 | -13.61 | -10.55 |
| copper | mm | -1.04 | -0.02 | -0.89 | -8.88 | -10.84 | -8.28 |
| BANGLADESH | 1974-87 | | | | | | |
| bananas | s | 0.01 | -0.01 | 0.05 | -1.87 | -1.69 | -1.80 |
| beef | s | -0.03 | 0.03 | 0.05 | -1.86 | -1.55 | -1.66 |
| jute | s | 0.15 | -0.13 | 0.08 | -0.70 | -2.32 | -1.27 |
| rice | s | -0.26 | -0.09 | -0.30 | -0.94 | -1.86 | -1.05 |
| sugar | s | -0.51 | -0.09 | -0.55 | -0.05 | -1.87 | -0.17 |
| KOREA | 1965-86 | | | | | | |
| rice | s | 0.35 | 0.11 | 1.44 | -0.49 | -0.95 | 2.11 |
| soybeans | s | -0.43 | -0.01 | 0.53 | -2.27 | -1.75 | -0.47 |
| wheat | s | 0.21 | -2.79 | -1.60 | -0.40 | -9.02 | -5.87 |
| iron ore | mm | 0.33 | -0.64 | 0.67 | -1.06 | -2.81 | -0.32 |
| MALAYSIA | 1964-86 | | | | | | |
| palm oil | x | 0.94 | -0.42 | 1.01 | 2.37 | -1.67 | 2.37 |
| rubber | x | 0.49 | -0.36 | 0.63 | 1.68 | -1.25 | 2.10 |
| rice | s | 0.69 | -0.52 | 0.66 | 1.84 | -1.81 | 1.69 |
| bauxite | mm | 0.00 | -0.29 | 0.21 | -0.60 | -1.35 | -0.48 |
| iron ore | mm | -0.49 | 0.18 | 0.19 | -1.44 | -0.32 | -0.10 |
| PAPUA NEW GUINEA | 1969-85 | | | | | | |
| cocoa | x | -0.32 | 0.09 | -0.35 | 0.43 | -0.96 | 0.20 |
| coffee | x | -0.37 | 0.21 | -0.28 | -0.33 | -0.50 | -0.09 |
| rubber | x | 0.47 | 0.30 | 0.65 | 1.43 | -0.22 | 1.95 |
| bananas | s | 0.20 | 0.11 | 0.20 | -0.56 | -0.72 | -0.54 |
| PHILIPPINES | 1964-87 | | | | | | |
| banana | x | 0.68 | -0.07 | 0.66 | 0.82 | -0.48 | 0.89 |
| sugar | x | 0.41 | 0.28 | 0.74 | 0.90 | 0.29 | 1.74 |
| maize | s | 1.23 | 0.17 | 1.45 | 2.03 | 0.13 | 2.70 |
| rice | s | 2.44 | 0.11 | 2.61 | 5.01 | -0.21 | 5.34 |

TABLE 1: RISK ADJUSTMENTS BY COUNTRY (%)

| Country/ Commodity | Period/ Type | Coefficient of Relative Risk Aversion (ρ) = 1 World Price | Quantity | Output Value | Coefficient of Relative Risk Aversion (ρ) = 2 World Price | Quantity | Output Value |
|---|---|---|---|---|---|---|---|
| SRI LANKA | 1964-84 | | | | | | |
| rubber | x | 0.55 | 0.17 | 0.69 | -0.37 | -0.90 | -0.25 |
| tea | x | 0.01 | 0.06 | 0.04 | -0.59 | -0.92 | -0.49 |
| rice | s | 0.64 | 0.27 | 0.89 | 0.41 | -0.79 | 0.64 |
| THAILAND | 1964-87 | | | | | | |
| maize | x | 0.14 | -0.04 | 0.17 | 0.45 | -0.51 | 0.34 |
| rice | x | 0.24 | 0.03 | 0.34 | 1.12 | -0.23 | 1.29 |
| rubber | x | 0.21 | -0.05 | 0.22 | 0.71 | -0.42 | 0.69 |
| TURKEY | 1965-87 | | | | | | |
| cotton | x | 0.05 | 0.50 | 0.30 | -1.37 | -0.48 | -0.76 |
| tobacco | x | 0.34 | 0.63 | 0.73 | -0.14 | -0.16 | 0.78 |
| maize | s | 0.30 | 0.45 | 0.51 | -0.73 | -0.71 | -0.35 |
| oranges | s | 0.14 | 0.10 | 0.00 | 0.74 | -1.27 | 0.55 |
| rice | s | -0.43 | 0.22 | -0.45 | -2.29 | -0.81 | -2.01 |
| wheat | s | 0.14 | 0.60 | 0.50 | -0.44 | -0.43 | 0.22 |
| iron ore | mm | 0.11 | 0.44 | 0.31 | -1.50 | -0.70 | -1.12 |
| ARGENTINA | 1964-86 | | | | | | |
| beef | x | -0.38 | -0.44 | -0.46 | -1.13 | -1.40 | -1.29 |
| maize | x | -0.13 | -0.52 | -0.29 | -0.46 | -1.64 | -0.86 |
| sorghum | x | -0.08 | -0.74 | -0.46 | -0.36 | -1.99 | -1.12 |
| wheat | x | -0.46 | -0.95 | -1.06 | -1.13 | -2.37 | -2.26 |
| cotton | s | 0.08 | -0.28 | 0.16 | -0.02 | -1.17 | 0.05 |
| rice | s | 0.15 | -0.37 | 0.14 | 0.31 | -1.47 | 0.08 |
| sugar | s | 0.76 | -0.06 | 1.06 | 1.42 | -0.61 | 2.05 |
| BRAZIL | 1966-86 | | | | | | |
| cocoa | x | 0.68 | -0.24 | 0.34 | 1.37 | -0.70 | 0.67 |
| coffee | x | 1.25 | -1.38 | -0.24 | 2.45 | -3.08 | -0.64 |
| cotton | x | 2.35 | 0.66 | 2.90 | 4.51 | 1.09 | 5.59 |
| soybeans | x | 1.04 | 0.90 | 1.83 | 1.97 | 1.46 | 3.43 |
| sugar | x | 1.10 | 0.00 | 0.99 | 2.02 | -0.23 | 1.79 |
| tobacco | x | -0.23 | 0.20 | -0.14 | -0.56 | 0.20 | -0.37 |
| beef | s | 1.10 | 0.01 | 1.01 | 2.13 | -0.21 | 1.91 |
| maize | s | 0.32 | 0.02 | 0.24 | 0.45 | -0.15 | 0.29 |
| rice | s | 0.68 | 0.66 | 1.23 | 1.29 | 1.14 | 2.42 |
| wheat | s | 0.71 | 2.23 | 2.84 | 1.38 | 4.26 | 5.64 |
| bauxite | mm | -0.71 | 0.74 | -0.07 | -1.35 | 1.17 | -0.19 |
| iron ore | mm | 0.77 | 1.16 | 1.83 | 1.38 | 2.18 | 3.55 |
| phosphate rock | mm | -0.50 | 0.83 | 0.23 | -1.04 | 1.38 | 0.34 |
| CHILE | 1964-86 | | | | | | |
| beef | s | -0.31 | -0.46 | 0.14 | -1.47 | -1.89 | -0.63 |
| maize | s | -0.65 | -0.16 | 0.09 | -2.39 | -1.18 | -0.84 |
| rice | s | 0.33 | -1.15 | 0.09 | -0.12 | -3.32 | -0.71 |
| wheat | s | -0.79 | -0.58 | -0.45 | -2.78 | -2.06 | -2.11 |
| copper | mm | -0.15 | -0.79 | -0.02 | -0.91 | -2.48 | -0.67 |
| iron ore | mm | -1.80 | -1.74 | -2.63 | -4.67 | -4.48 | -6.42 |
| COLOMBIA | 1964-86 | | | | | | |
| banana | x | -0.18 | -0.32 | -0.37 | -0.72 | -1.12 | -1.14 |
| coffee | x | 0.25 | -0.14 | 0.24 | 0.46 | -0.60 | 0.54 |
| cotton | x | 0.65 | 0.47 | 1.25 | 1.00 | 0.43 | 2.12 |
| beef | s | 1.01 | -0.08 | 1.12 | 1.73 | -0.46 | 1.96 |
| maize | s | 0.29 | -0.13 | 0.30 | 0.09 | -0.60 | 0.18 |
| rice | s | 0.59 | -0.04 | 0.69 | 0.98 | -0.58 | 1.14 |
| sugar | s | 0.39 | -0.08 | 0.45 | 0.52 | -0.66 | 0.55 |
| wheat | s | 0.67 | -0.19 | 0.62 | 0.91 | -0.99 | 0.61 |
| iron ore | mm | -1.40 | -0.17 | -1.42 | -3.29 | -0.74 | -3.33 |
| COSTA RICA | 1964-87 | | | | | | |
| banana | x | -0.23 | -0.38 | -0.15 | -1.08 | -1.80 | -1.05 |
| beef | x | -0.14 | 0.24 | 0.57 | -0.64 | -0.51 | 0.68 |
| cocoa | x | 1.28 | 0.00 | 1.74 | 2.50 | -0.69 | 3.63 |
| coffee | x | 0.93 | -0.54 | 0.86 | 2.00 | -2.05 | 1.77 |
| sugar | x | 0.15 | -0.26 | 0.36 | 0.50 | -1.38 | 0.94 |

**TABLE 1: RISK ADJUSTMENTS BY COUNTRY (%)**

| Country/ Commodity | Period/ Type | Coefficient of Relative Risk Aversion (p) = 1 | | | Coefficient of Relative Risk Aversion (p) = 2 | | |
|---|---|---|---|---|---|---|---|
| | | World Price | Quantity | Output Value | World Price | Quantity | Output Value |
| GUATEMALA | 1984-86 | | | | | | |
| banana | x | -0.09 | 0.37 | 0.33 | -0.37 | 0.59 | 0.48 |
| coffee | x | 1.64 | 0.12 | 1.82 | 3.06 | 0.09 | 3.42 |
| cotton | x | 1.02 | 1.77 | 2.85 | 1.84 | 3.49 | 5.60 |
| sugar | x | 0.84 | -0.32 | 0.58 | 1.55 | -0.79 | 1.03 |
| maize | s | 0.17 | -0.35 | -0.13 | 0.19 | -0.90 | -0.44 |
| MEXICO | 1984-86 | | | | | | |
| banana | s | -0.46 | -0.76 | -0.43 | -1.06 | -1.73 | -0.96 |
| beef | s | -0.46 | -1.04 | -0.70 | -1.14 | -2.28 | -1.59 |
| maize | s | -0.28 | -0.62 | -0.10 | -0.52 | -1.44 | -0.13 |
| sorghum | s | -0.60 | -0.32 | -0.12 | -1.20 | -0.79 | -0.16 |
| wheat | s | 0.04 | -0.59 | 0.24 | 0.07 | -1.46 | 0.43 |
| iron ore | mm | -0.31 | -0.98 | -0.49 | -0.82 | -2.23 | -1.22 |
| lead | mm | 0.09 | -0.50 | 0.39 | -0.04 | -1.21 | 0.58 |

## TABLE 2: RISK ADJUSTMENTS BY COMMODITY (%)

| Commodity/ Country | Type | Coefficient of Relative Risk Aversion (p) = 1: World Price | Quantity | Output Value | Coefficient of Relative Risk Aversion (p) = 2: World Price | Quantity | Output Value |
|---|---|---|---|---|---|---|---|
| **BANANAS** | | | | | | | |
| Cameroon | x | 3.12 | 1.45 | 2.14 | 5.63 | 2.31 | 3.85 |
| Cote D'Ivoire | x | 0.27 | 0.06 | 0.45 | -0.24 | -1.11 | 0.00 |
| Bangladesh | s | 0.01 | -0.01 | 0.05 | -1.87 | -1.69 | -1.80 |
| Papua New Guinea | s | 0.20 | 0.11 | 0.20 | -0.56 | -0.72 | -0.54 |
| Philippines | x | 0.68 | -0.07 | 0.66 | 0.82 | -0.48 | 0.89 |
| Colombia | x | -0.18 | -0.32 | -0.37 | -0.72 | -1.12 | -1.14 |
| Costa Rica | x | -0.23 | -0.38 | -0.15 | -1.08 | -1.80 | -1.05 |
| Guatemala | x | -0.09 | 0.37 | 0.33 | -0.37 | 0.59 | 0.48 |
| Mexico | s | -0.46 | -0.76 | -0.43 | -1.06 | -1.73 | -0.96 |
| **BEEF** | | | | | | | |
| Ethiopia | s | -0.09 | -0.05 | -0.07 | -0.15 | -0.27 | -0.05 |
| Kenya | s | 0.38 | 0.17 | 0.58 | 0.12 | -0.21 | 0.52 |
| Madagascar | x | -1.69 | -1.69 | -1.74 | -3.78 | -3.77 | -3.78 |
| Sudan | s | -2.80 | 0.34 | -2.57 | -6.17 | 0.11 | -5.80 |
| Bangladesh | s | -0.03 | 0.03 | 0.05 | -1.86 | -1.55 | -1.66 |
| Argentina | x | -0.38 | -0.44 | -0.46 | -1.13 | -1.40 | -1.29 |
| Brazil | s | 1.10 | 0.01 | 1.01 | 2.13 | -0.21 | 1.91 |
| Chile | s | -0.31 | -0.46 | 0.14 | -1.47 | -1.89 | -0.63 |
| Colombia | s | 1.01 | -0.03 | 1.12 | 1.73 | -0.46 | 1.96 |
| Costa Rica | x | -0.14 | 0.24 | 0.57 | -0.64 | -0.51 | 0.68 |
| Mexico | s | -0.46 | -1.04 | -0.70 | -1.14 | -2.28 | -1.59 |
| **COCOA** | | | | | | | |
| Cameroon | x | 5.88 | 9.99 | 13.44 | 10.77 | 19.17 | 25.85 |
| Cote D'Ivoire | x | -0.53 | -0.12 | -0.53 | -2.11 | -1.37 | -2.13 |
| Ghana | x | 0.38 | 1.25 | 0.90 | -4.27 | -2.79 | -3.30 |
| Nigeria | x | 1.47 | -1.83 | 0.80 | 2.31 | -5.29 | 0.86 |
| Papua New Guinea | x | -0.32 | 0.09 | -0.35 | 0.43 | -0.96 | 0.20 |
| Brazil | x | 0.68 | -0.24 | 0.34 | 1.37 | -0.70 | 0.67 |
| Costa Rica | x | 1.28 | 0.00 | 1.74 | 2.50 | -0.69 | 3.63 |
| **COFFEE** | | | | | | | |
| Cameroon | x | 5.00 | 2.36 | 4.93 | 9.19 | 3.97 | 9.07 |
| Cote D'Ivoire | x | -0.31 | 0.77 | 0.58 | -1.48 | 0.75 | 0.62 |
| Ethiopia | x | 0.05 | -0.09 | 0.03 | 0.31 | -0.40 | 0.28 |
| Kenya | x | -0.72 | 0.39 | -0.30 | -1.90 | 0.46 | -0.83 |
| Madagascar | x | -1.40 | -1.26 | -1.02 | -3.31 | -2.87 | -2.41 |
| Rwanda | x | 0.75 | 0.36 | 0.94 | 0.85 | 0.14 | 1.20 |
| Tanzania | x | 0.29 | -0.04 | 0.25 | 0.27 | -0.15 | 0.27 |
| Papua New Guinea | x | -0.37 | 0.21 | -0.28 | -0.33 | -0.50 | -0.09 |
| Brazil | x | 1.25 | -1.38 | -0.24 | 2.45 | -3.08 | -0.64 |
| Colombia | x | 0.25 | -0.14 | 0.24 | 0.46 | -0.60 | 0.54 |
| Costa Rica | x | 0.93 | -0.54 | 0.86 | 2.00 | -2.05 | 1.77 |
| Guatemala | x | 1.64 | 0.12 | 1.82 | 3.06 | 0.09 | 3.42 |
| **COTTON** | | | | | | | |
| Burkina Faso | x | 0.02 | 1.07 | 0.99 | -0.74 | 1.58 | 1.55 |
| Cameroon | x | 0.07 | 6.06 | 3.70 | -0.57 | 11.18 | 6.52 |
| Cote D'Ivoire | x | -0.03 | -0.25 | -0.16 | -1.34 | -1.51 | -1.50 |
| Malawi | x | 1.86 | -0.11 | 1.55 | 3.29 | -0.42 | 2.83 |
| Senegal | x | -0.84 | 0.50 | -0.58 | -3.31 | -1.04 | -3.47 |
| Sudan | x | -0.50 | -0.08 | -0.69 | -1.38 | -0.69 | -1.81 |
| Tanzania | x | 0.38 | 0.06 | 0.43 | 0.46 | -0.08 | 0.53 |
| Uganda | s | 2.79 | 3.43 | 4.91 | 5.53 | 6.78 | 9.74 |
| Turkey | x | 0.05 | 0.50 | 0.30 | -1.37 | -0.48 | -0.76 |
| Argentina | s | 0.08 | -0.28 | 0.16 | -0.02 | -1.17 | 0.05 |
| Brazil | x | 2.35 | 0.66 | 2.90 | 4.51 | 1.09 | 5.59 |
| Colombia | x | 0.65 | 0.47 | 1.25 | 1.00 | 0.43 | 2.12 |
| Guatemala | x | 1.02 | 1.77 | 2.85 | 1.84 | 3.49 | 5.60 |
| **GROUNDNUT OIL** | | | | | | | |
| Niger | x | -0.27 | 6.93 | 6.33 | -2.06 | 13.05 | 11.01 |
| Senegal | x | -1.25 | 0.41 | -1.08 | -5.23 | -0.20 | -4.54 |
| **JUTE** | | | | | | | |
| Bangladesh | s | 0.15 | -0.13 | 0.08 | -0.70 | -2.32 | -1.27 |

**TABLE 2: RISK ADJUSTMENTS BY COMMODITY (%)**

| Commodity/ Country | Type | Coefficient of Relative Risk Aversion (p) = 1 World Price | Quantity | Output Value | Coefficient of Relative Risk Aversion (p) = 2 World Price | Quantity | Output Value |
|---|---|---|---|---|---|---|---|
| **MAIZE** | | | | | | | |
| Cameroon | s | 6.88 | 2.24 | 6.69 | 12.87 | 3.71 | 12.49 |
| Cote D'Ivoire | s | 0.21 | -0.16 | 0.17 | -0.82 | -1.78 | -1.25 |
| Ethiopia | s | -0.06 | -0.08 | -0.07 | -0.14 | -0.51 | -0.28 |
| Ghana | s | 1.20 | 1.69 | 2.17 | -2.95 | -2.26 | -1.46 |
| Kenya | s | 0.89 | -0.23 | 0.70 | 1.74 | -1.26 | 1.10 |
| Madagascar | s | -1.75 | -1.70 | -1.81 | -3.84 | -4.01 | -4.08 |
| Malawi | x | 0.56 | 0.74 | 1.10 | 0.67 | 1.10 | 1.74 |
| Nigeria | s | 0.00 | -0.86 | 0.31 | -0.76 | -3.74 | -0.65 |
| Tanzania | s | 0.02 | 0.37 | 0.38 | -0.10 | 0.48 | 0.52 |
| Uganda | s | 1.94 | 2.18 | 2.81 | 3.88 | 4.30 | 5.56 |
| Zambia | s | -0.62 | 0.05 | -0.40 | -8.39 | -13.61 | -10.55 |
| Philippines | s | 1.23 | 0.17 | 1.46 | 2.03 | 0.13 | 2.70 |
| Thailand | x | 0.14 | -0.04 | 0.17 | 0.45 | -0.51 | 0.34 |
| Turkey | s | 0.30 | 0.45 | 0.51 | -0.73 | -0.71 | -0.35 |
| Argentina | x | -0.13 | -0.52 | -0.29 | -0.46 | -1.64 | -0.86 |
| Brazil | s | 0.32 | 0.02 | 0.24 | 0.45 | -0.15 | 0.29 |
| Chile | s | -0.65 | -0.18 | 0.09 | -2.39 | -1.18 | -0.84 |
| Colombia | s | 0.29 | -0.13 | 0.30 | 0.09 | -0.60 | 0.18 |
| Guatemala | s | 0.17 | -0.35 | -0.13 | 0.19 | -0.90 | -0.44 |
| Mexico | s | -0.28 | -0.62 | -0.10 | -0.52 | -1.44 | -0.13 |
| **ORANGES** | | | | | | | |
| Turkey | s | 0.14 | 0.10 | 0.00 | 0.74 | -1.27 | 0.55 |
| **PALM OIL** | | | | | | | |
| Cote D'Ivoire | x | -0.97 | 1.07 | 0.23 | -3.71 | 1.12 | -1.24 |
| Nigeria | x | 1.04 | -1.07 | 1.14 | 2.08 | -3.61 | 2.31 |
| Malaysia | x | 0.94 | -0.42 | 1.01 | 2.37 | -1.67 | 2.37 |
| **RICE** | | | | | | | |
| Cote D'Ivoire | s | 0.05 | -0.23 | -0.06 | -0.47 | -1.52 | -0.64 |
| Madagascar | s | -2.10 | -1.51 | -1.97 | -4.53 | -3.56 | -4.33 |
| Nigeria | s | -3.01 | -3.80 | -5.63 | -6.37 | -9.05 | -11.58 |
| Senegal | s | -2.15 | 0.09 | -2.30 | -4.88 | -1.41 | -5.40 |
| Tanzania | s | 0.10 | 0.01 | 0.09 | 0.41 | -0.30 | 0.26 |
| Korea | s | 0.35 | 0.11 | 1.44 | -0.49 | -0.95 | 2.11 |
| Malaysia | s | 0.69 | -0.52 | 0.66 | 1.84 | -1.81 | 1.69 |
| Philippines | s | 2.44 | 0.11 | 2.61 | 5.01 | -0.21 | 5.34 |
| Sri Lanka | s | 0.64 | 0.27 | 0.89 | 0.41 | -0.79 | 0.64 |
| Thailand | x | 0.24 | 0.03 | 0.34 | 1.12 | -0.23 | 1.29 |
| Turkey | s | -0.43 | 0.22 | -0.45 | -2.29 | -0.81 | -2.01 |
| Argentina | s | 0.15 | -0.37 | 0.14 | 0.31 | -1.47 | 0.08 |
| Brazil | s | 0.68 | 0.66 | 1.23 | 1.29 | 1.14 | 2.42 |
| Chile | s | 0.33 | -1.15 | 0.09 | -0.12 | -3.32 | -0.71 |
| Colombia | s | 0.59 | -0.04 | 0.69 | 0.98 | -0.53 | 1.14 |
| **RUBBER** | | | | | | | |
| Cameroon | x | 6.00 | -0.25 | 3.33 | 11.45 | -1.02 | 6.34 |
| Cote D'Ivoire | x | 0.29 | 0.21 | 0.63 | -0.08 | -0.54 | 0.73 |
| Malaysia | x | 0.49 | -0.36 | 0.63 | 1.68 | -1.25 | 2.10 |
| Papua New Guinea | x | 0.47 | 0.30 | 0.65 | 1.43 | -0.22 | 1.95 |
| Sri Lanka | x | 0.55 | 0.17 | 0.69 | -0.37 | -0.90 | -0.25 |
| Thailand | x | 0.21 | -0.05 | 0.22 | 0.71 | -0.42 | 0.69 |
| **SORGHUM** | | | | | | | |
| Burkina Faso | s | -0.18 | 0.31 | 0.02 | -0.67 | -0.25 | -0.21 |
| Ethiopia | s | -0.05 | -0.11 | -0.09 | -0.14 | -0.62 | -0.39 |
| Ghana | s | 1.41 | 1.96 | 2.65 | -2.31 | -1.87 | -0.43 |
| Kenya | s | 0.70 | -0.31 | 0.42 | 1.11 | 0.14 | 1.86 |
| Niger | s | -1.09 | 2.13 | 0.71 | -2.87 | 3.61 | 0.75 |
| Nigeria | s | -0.25 | -0.11 | 0.80 | -1.31 | -1.62 | 0.90 |
| Rwanda | s | 0.07 | 0.29 | 0.19 | -0.22 | -0.09 | -0.10 |
| Sudan | x | -2.34 | 0.98 | -1.46 | -5.25 | 1.46 | -3.54 |
| Tanzania | s | 0.00 | -0.02 | -0.03 | -0.08 | -0.02 | 0.04 |
| Uganda | s | 2.10 | 1.61 | 2.40 | 4.16 | 3.17 | 4.76 |
| Argentina | x | -0.08 | -0.74 | -0.46 | -0.36 | -1.99 | -1.12 |
| Mexico | s | -0.60 | -0.32 | -0.12 | -1.20 | -0.79 | -0.16 |

TABLE 2: RISK ADJUSTMENTS BY COMMODITY (%)

| Commodity/ Country | Type | Coefficient of Relative Risk Aversion (p) = 1 World Price | Quantity | Output Value | Coefficient of Relative Risk Aversion (p) = 2 World Price | Quantity | Output Value |
|---|---|---|---|---|---|---|---|
| **SOYBEANS** | | | | | | | |
| Korea | s | -0.43 | -0.01 | 0.53 | 2.27 | -1.75 | -0.47 |
| Brazil | x | 1.04 | 0.90 | 1.83 | 1.97 | 1.46 | 3.43 |
| **SUGAR** | | | | | | | |
| Ethiopia | s | -0.28 | 0.06 | -0.15 | -0.70 | -0.12 | -0.44 |
| Kenya | s | 1.16 | -0.28 | 0.91 | 2.94 | -0.82 | 2.74 |
| Madagascar | x | -1.06 | -1.49 | -0.91 | -2.34 | -4.14 | -2.72 |
| Sudan | s | 1.82 | -1.40 | 0.31 | 3.40 | -3.31 | 0.35 |
| Tanzania | s | 0.03 | -0.03 | -0.02 | 0.16 | -0.28 | 0.03 |
| Uganda | s | 1.78 | 1.19 | 1.66 | 3.52 | 2.32 | 3.28 |
| Bangladesh | s | -0.51 | -0.09 | -0.55 | -0.05 | -1.87 | -0.17 |
| Philippines | x | 0.41 | 0.28 | 0.74 | 0.90 | 0.29 | 1.74 |
| Argentina | s | 0.76 | -0.06 | 1.06 | 1.42 | -0.61 | 2.05 |
| Brazil | x | 1.10 | 0.00 | 0.98 | 2.02 | -0.23 | 1.79 |
| Colombia | s | 0.39 | -0.08 | 0.45 | 0.52 | -0.66 | 0.55 |
| Costa Rica | x | 0.15 | -0.26 | 0.36 | 0.50 | -1.38 | 0.94 |
| Guatemala | x | 0.84 | -0.32 | 0.58 | 1.55 | -0.79 | 1.03 |
| **TEA** | | | | | | | |
| Kenya | x | 0.00 | -0.01 | 0.02 | 0.20 | -0.62 | 0.20 |
| Malawi | x | 0.53 | 0.35 | 0.69 | 1.22 | 0.19 | 1.37 |
| Rwanda | x | -0.68 | 0.24 | -0.61 | -1.85 | 0.02 | -1.62 |
| Tanzania | x | 0.02 | 0.10 | 0.12 | -0.25 | 0.09 | -0.01 |
| Sri Lanka | x | 0.01 | 0.06 | 0.04 | -0.59 | -0.92 | -0.49 |
| **TOBACCO** | | | | | | | |
| Malawi | x | 1.00 | -0.59 | 0.22 | 1.82 | -1.33 | 0.45 |
| Tanzania | x | 0.06 | 0.03 | 0.08 | 0.22 | -0.19 | 0.18 |
| Turkey | x | 0.34 | 0.63 | 0.73 | -0.14 | -0.16 | 0.78 |
| Brazil | x | -0.23 | 0.20 | -0.14 | -0.56 | 0.20 | -0.37 |
| **WHEAT** | | | | | | | |
| Ethiopia | s | -0.24 | 0.04 | -0.12 | -0.42 | -0.09 | -0.13 |
| Korea | s | 0.21 | -2.79 | -1.60 | -0.40 | -9.02 | -5.87 |
| Turkey | s | 0.14 | 0.60 | 0.50 | -0.44 | -0.43 | 0.22 |
| Argentina | x | -0.46 | -0.95 | -1.06 | -1.13 | -2.37 | -2.26 |
| Brazil | s | 0.71 | 2.23 | 2.84 | 1.38 | 4.26 | 5.64 |
| Chile | s | -0.79 | -0.58 | -0.45 | -2.78 | -2.06 | -2.11 |
| Colombia | s | 0.67 | -0.19 | 0.62 | 0.91 | -0.99 | 0.61 |
| Mexico | s | 0.04 | -0.59 | 0.24 | 0.07 | -1.46 | 0.43 |
| **BAUXITE** | | | | | | | |
| Ghana | mm | 1.19 | 3.46 | 3.92 | -2.93 | 2.96 | 3.77 |
| Malaysia | mm | 0.00 | -0.29 | 0.21 | -0.80 | -1.35 | -0.48 |
| Brazil | mm | -0.71 | 0.74 | -0.07 | -1.35 | 1.17 | -0.19 |
| **COPPER** | | | | | | | |
| Zambia | mm | -1.04 | -0.02 | -0.89 | -8.88 | -10.84 | -8.28 |
| Chile | mm | -0.15 | -0.79 | -0.02 | -0.91 | -2.48 | -0.67 |
| **CRUDE PETROLEUM** | | | | | | | |
| Nigeria | mm | 3.11 | 4.52 | 8.79 | 6.99 | 8.50 | 19.33 |
| **IRON ORE** | | | | | | | |
| Korea | mm | 0.33 | -0.64 | 0.67 | -1.06 | -2.81 | -0.32 |
| Malaysia | mm | -0.49 | 0.18 | 0.19 | -1.44 | -0.32 | -0.10 |
| Turkey | mm | 0.11 | 0.44 | 0.31 | -1.50 | -0.70 | -1.12 |
| Brazil | mm | 0.77 | 1.16 | 1.83 | 1.38 | 2.18 | 3.55 |
| Chile | mm | -1.80 | -1.74 | -2.63 | -4.67 | -4.48 | -6.42 |
| Colombia | mm | -1.40 | -0.17 | -1.42 | -3.29 | -0.74 | -3.33 |
| Mexico | mm | -0.31 | -0.98 | -0.49 | -0.82 | -2.23 | -1.22 |
| **LEAD** | | | | | | | |
| Mexico | mm | 0.09 | -0.50 | 0.39 | -0.04 | -1.21 | 0.58 |
| **PHOSPHATE ROCK** | | | | | | | |
| Senegal | mm | -0.61 | -0.23 | -1.08 | -3.42 | -1.86 | -4.40 |
| Brazil | mm | -0.50 | 0.83 | 0.28 | -1.04 | 1.38 | 0.34 |

between the uncertainty in the project and in GNP. All three are large in the case of crude oil production in Nigeria (see Annex 2). The table does show quite significant risk adjustments for this case. For example, in the case of world price uncertainty with $\rho = 2$, nearly seven percentage points must be added to the riskless rate when judging a crude oil project in Nigeria.

But the same does not apply to other highly specialized countries. For example, when $\rho = 2$, cocoa projects in Ghana and copper projects in Zambia have some large and negative risk adjustment terms. This result is due primarily to large error variance multipliers for the real exchange rates (that is, large values of $\sigma_{11}$) in both cases. The intuition that further investment in a crop or a sector that constitutes a large part of a country's GNP will have a large systematic risk is not invalid, but this effect may be offset or overridden by other forces that operate at the same time. Therefore, a reliable estimate of project risk requires careful and systematic examination of all these effects and of their interactions.

The second point is to stress that risk corrections can be negative. This can happen because of exchange risk as explained above, but a more direct cause is a negative correlation between project risk and GNP risk. Intuitively, the project is especially attractive when its inclusion reduces the overall risk. Some examples are rice in Nigeria and groundnut oil in Senegal. Since projects with negative risk adjustments are especially attractive, it will be useful to know how they can be generated and identified.

Third, the risk corrections vary quite widely across countries and sectors. Therefore an undifferentiated treatment of uncertainty by the inclusion of a common adjustment for risk in the target rate of return on all projects in all countries is likely to lead to significant errors of commission as well as omission. Therefore we believe that the practicality of a more selective approach such as that explored here should be examined in more detail.

The differences arise in different dimensions that are worth further comment. (1) In one country, there are differences across sectors because of different sectoral uncertainty and different correlations with GNP. To give just one example, in Nigeria the risk correction varies from plus seven percentage points for crude petroleum to minus six for rice (price shock, $\rho = 2$). (2) For a given product, there are differences across countries because of different country GNP uncertainty and its correlation with the product price. For example, for maize the risk adjustment varies from plus thirteen (Cameroon) to minus four (Madagascar).

For a given country and sector, the correction terms depends on the nature of the uncertainty. For example, for wheat in Korea the adjustment is nearly zero for world price uncertainty, but large and negative for quantity uncertainty. We expect this difference because world price uncertainty generally reflects a demand shock from the perspective of the country in question, while quantity uncertainty is a supply shock. But in many other cases the differences are much smaller (one-half percentage point or less). If we can systematically identify cases where the nature of the uncertainty does not make a substantial difference, the method will be much easier to implement.

A fourth and last point about the results is that the risk correction terms are small for many of the sectors and countries, but there are other cases in which the proposed treatment of risk makes a significant difference. Implementation of a systematic treatment of risk in project appraisal will be greatly simplified if a general class of country and sector combinations for which risk can safely be neglected can be identified so that efforts can be concentrated on the remaining categories where it does matter.

## VI. DIRECTIONS FOR FURTHER WORK

We believe that the exploratory research has yielded results of sufficient interest and promises to warrant further and more detailed study. Some ideas for this emerge naturally from the work reported here.

The first step is to improve the procedure for forecasting the coefficients of variation and the correlation coefficients. We ran a least squares regression for each time series by itself and then put together the residuals to calculate covariances. A vector autoregression, or treating several time series as a system of seemingly unrelated regressions, would be an improvement but was too time-consuming for a pilot study. Even more general methods, including analogs of the estimation of time-varying betas in financial economics (Szeto, 1973), or more sophisticated time series specifications like the ARCH model of Engle (1982), can also be tried if the work proceeds.

Our next suggestion is to use this method to carry out fresh *ex ante* appraisals of some projects previously examined in the Bank. This will show how the incorporation of risk considerations alters the assessment of some actual projects. We may even find a partial explanation of the discrepancy between the appraised and realized rates of return that was found by Pohl (1988). Alternatively, or simultaneously, the method might be tested on some projects currently being appraised, with the aim of learning about its practical potential.

Improvements of the theoretical framework are also necessary. The pilot model used in this experiment used the minimal two-period setting in which the investment was made in the first period and the payoffs accrued in the second. In applying the model, the interpretation of the periods had to be stretched. We should refine the model to give explicit recognition to the multi-period nature of investment and payoffs. Again the analogy with the intertemporal capital asset pricing model of finance theory should be exploited. The model also assumed that the social objective could be expressed as a function of the aggregate quantity of consumption, thus neglecting the question of the distribution of risk among different groups in the country. This bears improvement, at least to a point where the treatment of the distribution of risk parallels that of the distribution of income in the Bank's procedures for project appraisal.

In conclusion, we offer a speculation about the way in which, and the extent to which, calculations of the kind developed in this report can be incorporated into the Bank's project appraisal procedures. Risk affects investment projects in many different and subtle ways. Therefore one should not aim for a simple table of risk adjustment terms that officers in the field could read in a manual and apply directly. Even when the procedure is refined as much as possible, each case will probably need some economic analysis and oversight. However, we think the resource requirements of this are quite modest. If further analysis reveals that the approach has merit, we believe routines would evolve to a point where for each project presented for appraisal, one professional economist would be able to incorporate the elements of risk into the forecasts of its costs and benefits, and judge if they modify its acceptability, in less than a week.

## VII. SOME SUGGESTIONS FOR PROJECT DESIGN

The main purpose of this research is to develop a practicable approach to the treatment of risk in appraising projects. But the approach has useful implications for the prior step of designing worthwhile projects. The aspect of risk that is relevant is the correlation between the project risk and that of national income. When this is positive, the project should pay more than the riskless rate of return to justify itself. But when the correlation is negative, the project can be acceptable even if its expected return is somewhat below the riskless rate. In other words, projects whose returns are negatively correlated with national income are particularly desirable from the economy's viewpoint. Intuitively, this is because their inclusion in the portfolio of projects reduces the overall risk. Social planners, and the Bank, should attempt to locate and develop such projects.

As in financial theory, diversification is an important principle for project design. Roughly, countries should be wary of expanding the sectors where they already have a lot of investment and attempt to produce a mix of outputs whose risks are unrelated or negatively related among themselves. However, this often conflicts with other considerations.

Countries may find it desirable or even necessary to specialize in one or a small number of sectors because of the availability of natural resource deposits or suitable land or climate and the existence of economies of scale.

A different way to put together projects whose returns are negatively correlated can emerge from consideration of the vertical structure of production. As an example, think of two vertical stages in the production of tea: growing tea leaves, and processing and packaging the tea. Each activity is risky; how are the risks correlated with each other?

The answer depends on the nature of shocks that cause the values added at the two stages to fluctuate. Suppose we are looking at the projects from the point of view of one country (for example, Sri Lanka). First consider the case in which the primary cause of fluctuation is a random change of consumer tastes between tea and coffee. An upward shift of demand for tea will raise the derived demand for tea leaves as well as the demand for other factors used in the processing and packaging stage. The correlation between the returns to the two stages will be positive. In contrast, consider the case in which the price of the final product is quite stable but the uncertainty resides in the production of tea leaves in other countries, and therefore in the price of tea leaves. When this price is low, returns to the upstream (tea growing) projects will be low, but those in the downstream (processing) industry will be high. The opposite will happen when the price of tea leaves is high. Thus the returns at the two vertical stages of production will be negatively correlated. This kind of analysis applies to many other cases of agriculture and agribusiness, as well as mining and metallurgical industries.

Which of these is the more likely scenario is an empirical question well worth investigation. If important sectors in which successive vertical stages have negatively correlated returns can be identified, the Bank will be able to help countries reduce their total risk by undertaking projects that span the stages.

# TECHNICAL APPENDIX

## Derivation of the CAPM-type formula

We use the standard two-period model, where the project investment is made in the first period and the payoff accrues in the second period. In each period there is other stochastic income; this allows us to think of the model as a subsection of an ongoing economy with other risky investments.

In each period there are two kinds of goods, traded and domestic. Traded goods are measured in units of constant dollars, and non-traded goods in units of constant domestic currency. The real exchange rate in period 1 is known and can be set equal to one without loss of generality. Let e denote the real exchange rate for period 2; it is unknown (a random variable) when the project is appraised.

Suppose first-period income (which can be stochastic) is $Y_1$. Of this, X is invested in the project question, and B in the riskless asset. (If there is no riskless asset, the analysis is more complicated but similar results can be obtained using the minimum-variance portfolio instead.) The first-period consumption is

$$C_1 = Y_1 - B - X \tag{A.1}$$

In the second period, there will be an exogenous stochastic income $A_2(e)$; the functional dependence allows this income to arise from any mixture of domestic and traded goods output. There will also be the sure return $(1+r)B$ from the riskless asset and the risky return from the project. In our applications the output of the risky project is in the form of traded goods. Let the dollar return be $pqF(X)$, where $F(X)$ is non-random, $p$ is a multiplicative shock representing a random world price, and $q$ is a multiplicative productivity shock (common to all production of this sector in this country). Finally, $pqF(X)$ must be multiplied by $e$ to convert it into domestic units.

Although we do not do so in the specific applications, we could also allow the world price to depend on the output realization. For example, suppose all output risk in the country is perfectly correlated, and the world output risk has correlation $\gamma$ with this country's output risk. Suppose the world market demand is non-random and has elasticity $\epsilon$. Then the multiplicative revenue risk factor is the output risk factor raised to the power $(1-\gamma/\epsilon)$.

With this specification, the random second-period consumption $C_2$ (which equals second period income $Y_2$) measured in constant domestic currency units is

$$C_2 = Y_2 = A_2(e) + (1+r)B + epqF(X). \qquad (A.2)$$

The social optimization problem is to choose B and X to maximize

$$EU(C_1) + \delta\, E[U(C_2/\phi(e))], \qquad (A.3)$$

where $\delta$ is the social discount factor, $\phi(e)$ is the consumer price index and E denotes the mathematical expectation operator. In our applications, we will take each period's preferences to be Cobb-Douglas in traded and domestic goods, so $\phi(e) \sim e^{\alpha}$ where $\alpha$ is the share of traded goods in total consumption.

The first-order conditions are

$$-E[U'(C_1)] + \delta\ (1+r)\ E\left[\frac{1}{\phi(e)}\ U'\left(\frac{C_2}{\phi(e)}\right)\right] = 0, \tag{A.4}$$

and

$$-E[U'(C_1)] + \delta\ F'(X)\ E\left[\frac{epq}{\phi(e)}\ U'\left(\frac{C_2}{\phi(e)}\right)\right] = 0. \tag{A.5}$$

These combine to yield

$$\frac{1 + r}{E[epq]\ F'(X)} = \frac{E\left[\frac{epq}{\phi(e)}\ U'\left(\frac{C_2}{\phi(e)}\right)\right]}{E\left[epq\right]\ E\left[\frac{1}{\phi(e)}\ U'\left(\frac{C_2}{\phi(e)}\right)\right]}. \tag{A.6}$$

This can be expressed in ways that are useful in practice by (a) imposing special functional forms for U and $\phi$, and (b) assuming particular distributions for the random variables e, p, q and $C_2$, or (c) taking Taylor series approximations. The simplest CAPM framework assumes that U is quadratic, or can be approximated by a quadratic; accordingly no special assumptions need to be made about the distributions of the random variables. An alternative, especially useful in the intertemporal version of the CAPM, is to assume that U exhibits constant absolute risk aversion, and that the random variables are normally distributed For our purpose, it is most convenient to assume constant <u>relative</u> risk aversion and that the random variables are lognormally distributed. We should remind readers that we are not trying to build a universally valid theory, but are suggesting special cases and approximations. Their validity must be judged by testing them on actual data, and they must be modified in the light of such experience.

Thus suppose

$$U(z) = \begin{cases} \frac{1}{1-\rho} z^{1-\rho} & \text{when } \rho \neq 1 \\ \ln(z) & \text{when } \rho = 1. \end{cases} \tag{A.7}$$

Then

$$U'(z) = z^{-\rho}, \tag{A.8}$$

where $\rho$ is the coefficient of relative risk aversion.

With this functional form, and the Cobb-Douglas consumer price index introduced earlier, the right hand side of (A.6) can be written as

$$\frac{E[e^{1+\alpha(\rho-1)}\ p\ q\ C_2^{-\rho}]}{E[epq]\ E[e^{\alpha(\rho-1)}\ C_2^{-\rho}]}. \tag{A.9}$$

Next we assume a joint lognormal distribution for the random variables in (A.9):

$$(\ln(e),\ \ln(p),\ \ln(q),\ \ln(C_2)) \sim N(\nu,\Sigma), \tag{A.10}$$

where $\nu$ is the four-dimensional vector of means, and $\Sigma$ is is the four-by-four positive definite variance-covariance matrix. Note that in a strictly interpreted two-period model, there is no saving in period 2, so consumption $C_2$ equals income $Y_2$. The numerical calculations in the text assume this as an approximation, even though the two-period interpretation is looser.

Now we use the following mathematical result:

Lemma: Suppose the random vector x has multivariate normal distribution with mean $\nu$ and variance-covariance matrix $\Sigma$. Let $\beta$ be a constant vector. Then

$$E[\exp(\beta' x)] = \exp(\beta'\nu + \tfrac{1}{2}\beta'\Sigma\beta).$$

Using this, the natural logarithm of (A.9) can be simplified to

$$\alpha(\rho-1)[\sigma_{11} + \sigma_{12} + \sigma_{13}] - \rho[\sigma_{14} + \sigma_{24} + \sigma_{34}]. \qquad \text{(A.11)}$$

Now consider the left hand side of (A.6). If we write $\mu$ for the expected rate of return on the risky project, we have

$$E(epq)F'(X) = 1 + \mu,$$

and the natural logarithm of the left hand side of (A.6), for small r and $\mu$, is simply $(r-\mu)$. Finally, combining this with (A.11), we have the expression for a risk adjustment term for the project, that is, the amount by which the expected rate of return on this project should exceed the riskless rate of return:

$$\mu - r = \rho[\sigma_{14} + \sigma_{24} + \sigma_{34}] - \alpha(\rho-1)[\sigma_{11} + \sigma_{12} + \sigma_{13}]. \qquad \text{(A.12)}$$

## ANNEX 1

### DEFINITION OF WORLD PRICES

| COMMODITY | UNIT | DEFINITION |
|---|---|---|
| bananas | $/mt | Central and South American, first-class quality tropical pack, importer's price to jobber of processor, FOB U.S. ports; beginning January 1987, prices have been estimated based on average wholesale prices at New York City and Chicago. |
| beef | c/kg | U.S., imported frozen boneless, 85 percent visible lean cow meat, FOB port of entry. |
| cocoa | c/kg | daily price, average, New York and London, nearest 3 future trading months. |
| coconut oil | $/mt | Philippines/Indonesia, bulk, CIF Rotterdam. |
| coffee | c/kg | indicator price, other mild arabicas, average New York and Bremen/Hamburg markets, ex-dock. |
| copra | $/mt | Philippines/Indonesian, bulk, CIF N.W. Europe. |
| cotton | c/kg | "Cotton Outlook", "A" index, middling (1-3/32"), CIF Europe. |
| groundnut oil | $/mt | any origin, CIF Rotterdam |
| jute | $/mt | Bangladesh, white D, FOB Chittagong/Chalna. |
| maize | $/mt | U.S., No. 2 yellow, FOB U.S. gulf ports. |
| oranges | $/mt | Mediterranean exporters, navel, EEC indicative import price, CIF Paris. |
| palm oil | $/mt | Malaysian, 5 percent bulk, CIF N.W. Europe. |
| rice | $/mt | Thai, white milled, 5 percent broken, government standard, export price, FOB Bangkok. |
| rubber | c/kg | RSS No. 1, in bales, sport, New York. |

| | | |
|---|---|---|
| sorghum | $/mt | U.S., No. 2 Milo yellow, FOB gulf prices. |
| soybean oil | $/mt | dutch, crude, FOB ex-mill. |
| soybeans | $/mt | U.S., CIF Rotterdam. |
| sugar | c/kg | world, ISA daily price, FOB and stowed at Greater Caribbean ports. |
| tea | c/kg | London auctions, price received for all tea. |
| wheat | $/mt | Canadian, No. 1, western red spring (cwrs), in store, Thunder Bay; from April 1985, St. Lawrence export. |

COMMODITY DEFINITION DIFFERENCES

| TYPE | FAO PRODUCTION | WORLD BANK WORLD PRICES |
|---|---|---|
| beef | beef and veal | frozen boneless |
| cocoa | cocoa beans | cocoa |
| coffee | coffee/green beans | coffee |
| cotton | seed cotton | cotton middling |
| rice | paddy rice | white milled rice |
| rubber | natural rubber | rubber |
| sugar | sugar cane | sugar |

## ANNEX 2: COMPONENTS OF THE RISK ADJUSTMENTS

| ountry/ Commodity | Period/ Type | CV of the real exchange rate | CV of GNP | Correlation between project shock and GNP | CV of project shock | CV of world price | CV of production |
|---|---|---|---|---|---|---|---|
| BURKINA FASO | 1964-87 | 10.18 | 3.44 | | | | |
| cotton | x | | | 0.20 | 28.22 | 19.13 | 24.84 |
| sorghum | s | | | 0.04 | 16.25 | 14.34 | 13.72 |
| CAMEROON | 1965-87 | 13.28 | 5.40 | | | | |
| bananas | x | | | -0.07 | 19.09 | 8.84 | 16.25 |
| cocoa | x | | | 0.71 | 28.41 | 25.15 | 10.09 |
| coffee | x | | | 0.17 | 24.17 | 25.85 | 16.35 |
| cotton | x | | | 0.18 | 24.32 | 19.52 | 23.28 |
| rubber | x | | | 0.00 | 24.94 | 20.28 | 14.92 |
| maize | s | | | 0.21 | 20.44 | 16.24 | 11.82 |
| COTE D'IVOIRE | 1964-87 | 9.76 | 4.18 | | | | |
| bananas | x | | | 0.42 | 13.18 | 8.70 | 10.53 |
| cocoa | x | | | -0.12 | 27.34 | 24.85 | 12.80 |
| coffee | x | | | 0.28 | 42.40 | 25.72 | 27.87 |
| cotton | x | | | -0.01 | 27.75 | 19.13 | 19.83 |
| palm oil | x | | | 0.04 | 28.02 | 22.94 | 15.67 |
| rubber | x | | | 0.28 | 21.99 | 19.86 | 13.37 |
| maize | s | | | 0.09 | 18.21 | 15.91 | 11.84 |
| rice | s | | | -0.01 | 23.13 | 24.12 | 12.91 |
| :IOPIA | 1964-83 | 4.08 | 1.77 | | | | |
| coffee | x | | | 0.09 | 24.25 | 22.02 | 8.11 |
| beef | s | | | 0.01 | 18.66 | 16.57 | 6.21 |
| maize | s | | | 0.00 | 19.23 | 15.50 | 13.82 |
| sorghum | s | | | -0.02 | 21.48 | 13.68 | 17.95 |
| sugar | s | | | -0.10 | 30.46 | 29.83 | 7.57 |
| wheat | s | | | 0.01 | 20.58 | 16.16 | 11.45 |
| GHANA | 1964-87 | 24.69 | 5.11 | | | | |
| cocoa | x | | | 0.07 | 26.79 | 25.23 | 13.90 |
| maize | s | | | 0.48 | 32.61 | 16.55 | 29.05 |
| sorghum | s | | | 0.50 | 34.90 | 14.97 | 31.89 |
| bauxite | mm | | | 0.30 | 44.90 | 16.53 | 37.05 |
| :YA | 1967-85 | 6.28 | 4.99 | | | | |
| coffee | x | | | -0.06 | 28.08 | 23.22 | 11.07 |
| tea | x | | | 0.02 | 25.74 | 20.26 | 13.18 |
| beef | s | | | 0.18 | 21.23 | 16.55 | 11.35 |
| maize | s | | | -0.02 | 21.77 | 17.33 | 15.41 |
| sorghum | s | | | 0.04 | 33.66 | 15.72 | 29.33 |
| sugar | s | | | 0.21 | 36.79 | 34.19 | 12.59 |
| MADAGASCAR | 1964-82 | 5.83 | 3.95 | | | | |
| beef | x | | | -0.05 | 16.17 | 16.42 | 3.64 |
| coffee | x | | | 0.29 | 23.73 | 21.29 | 7.17 |
| sugar | x | | | 0.26 | 34.32 | 30.23 | 7.68 |
| maize | s | | | -0.10 | 17.57 | 15.64 | 8.51 |
| rice | s | | | -0.12 | 24.05 | 23.73 | 3.32 |
| MALAWI | 1964-87 | 6.09 | 5.95 | | | | |
| cotton | x | | | 0.24 | 25.02 | 19.13 | 26.06 |
| maize | x | | | 0.30 | 18.06 | 15.91 | 11.13 |
| tea | x | | | 0.12 | 22.48 | 19.51 | 7.66 |
| tobacco | x | | | -0.06 | 17.62 | 9.83 | 18.09 |
| NIGER | 1966-87 | 9.45 | 6.73 | | | | |
| groundnut oil | x | | | 0.58 | 46.02 | 23.97 | 39.64 |
| sorghum | s | | | 0.50 | 20.54 | 14.96 | 22.20 |
| NIGERIA | 1964-85 | 11.87 | 7.66 | | | | |
| cocoa | x | | | 0.21 | 27.00 | 25.14 | 17.84 |
| palm oil | x | | | 0.30 | 21.92 | 22.55 | 5.44 |
| maize | s | | | 0.11 | 37.64 | 16.22 | 30.49 |
| rice | s | | | -0.31 | 33.89 | 25.16 | 18.95 |
| sorghum | s | | | 0.28 | 24.09 | 14.74 | 19.19 |
| crude petroleum | mm | | | 0.60 | 49.09 | 29.65 | 34.82 |

| Country/ Commodity | Period/ Type | CV of the real exchange rate | CV of GNP | Correlation between project shock and GNP | CV of project shock | CV of world price | CV o produc |
|---|---|---|---|---|---|---|---|
| RWANDA | 1969-87 | 16.17 | 8.72 | | | | |
| coffee | x | | | 0.13 | 31.66 | 28.40 | |
| tea | x | | | -0.18 | 19.80 | 21.23 | |
| sorghum | s | | | 0.03 | 14.68 | 15.85 | |
| SENEGAL | 1970-87 | 12.21 | 4.87 | | | | |
| cotton | x | | | -0.07 | 34.77 | 19.34 | |
| groundnut oil | x | | | -0.22 | 39.38 | 26.45 | |
| rice | s | | | -0.49 | 36.31 | 27.77 | |
| phosphate rock | mm | | | -0.37 | 39.63 | 32.14 | |
| SUDAN | 1964-87 | 11.50 | 6.62 | | | | |
| cotton | x | | | -0.10 | 29.03 | 19.13 | |
| sorghum | x | | | 0.00 | 35.69 | 14.34 | |
| beef | s | | | -0.44 | 15.73 | 16.29 | |
| sugar | s | | | 0.04 | 36.29 | 31.63 | |
| TANZANIA | 1968-85 | 6.36 | 1.67 | | | | |
| coffee | x | | | 0.24 | 20.44 | 23.82 | |
| cotton | x | | | 0.23 | 29.66 | 18.81 | |
| tea | x | | | 0.11 | 24.81 | 20.78 | |
| tobacco | x | | | 0.08 | 18.20 | 9.46 | |
| maize | s | | | 0.49 | 15.52 | 17.18 | |
| rice | s | | | 0.05 | 26.20 | 27.05 | |
| sorghum | s | | | -0.03 | 26.02 | 16.10 | |
| sugar | s | | | -0.02 | 36.28 | 35.13 | |
| UGANDA | 1970-87 | 48.65 | 4.50 | | | | |
| coffee | x | | | 0.15 | 31.84 | 29.17 | |
| cotton | s | | | 0.40 | 56.28 | 21.88 | |
| maize | s | | | 0.40 | 24.65 | 17.50 | |
| sorghum | s | | | 0.20 | 30.51 | 16.15 | |
| sugar | s | | | 0.08 | 32.61 | 35.62 | |
| ZAMBIA | 1964-86 | 26.68 | 5.47 | | | | |
| maize | s | | | -0.01 | 21.68 | 16.20 | |
| copper | mm | | | -0.18 | 24.36 | 22.30 | |
| BANGLADESH | 1974-87 | 20.37 | 1.83 | | | | |
| bananas | s | | | 0.18 | 10.44 | 8.95 | |
| beef | s | | | 0.14 | 20.17 | 16.06 | |
| jute | s | | | 0.12 | 22.22 | 20.17 | |
| rice | s | | | -0.24 | 21.30 | 21.00 | |
| sugar | s | | | -0.32 | 38.41 | 39.27 | |
| KOREA | 1965-86 | 6.81 | 16.61 | | | | |
| rice | s | | | 0.24 | 24.62 | 25.15 | |
| soybeans | s | | | 0.22 | 18.45 | 18.87 | |
| wheat | s | | | -0.02 | 55.13 | 17.05 | |
| iron ore | mm | | | 0.25 | 15.93 | 11.04 | |
| MALAYSIA | 1964-86 | 6.67 | 2.59 | | | | |
| palm oil | x | | | 0.49 | 23.59 | 23.15 | |
| rubber | x | | | 0.45 | 23.92 | 20.27 | |
| rice | s | | | 0.29 | 26.82 | 24.63 | |
| bauxite | mm | | | 0.20 | 31.73 | 16.17 | |
| iron ore | mm | | | 0.13 | 45.97 | 10.81 | |
| PAPUA NEW GUINEA | 1969-85 | 8.94 | 2.74 | | | | |
| cocoa | x | | | -0.27 | 25.69 | 25.67 | |
| coffee | x | | | 0.55 | 24.10 | 24.51 | |
| rubber | x | | | 0.25 | 31.16 | 22.92 | |
| bananas | s | | | 0.09 | 9.40 | 9.42 | |
| PHILIPPINES | 1964-87 | 8.45 | 2.88 | | | | |
| banana | x | | | 0.26 | 13.38 | 8.70 | |
| sugar | x | | | 0.13 | 35.91 | 31.63 | |
| maize | s | | | 0.30 | 19.23 | 15.91 | |
| rice | s | | | 0.42 | 26.00 | 24.12 | |

| try/ ommodity | Period/ Type | CV of the real exchange rate | CV of GNP | Correlation between project shock and GNP | CV of project shock | CV of world price | CV of production |
|---|---|---|---|---|---|---|---|
| LANKA | 1964-84 | 12.14 | 1.94 | | | | |
| rubber | x | | | 0.48 | 22.79 | 20.57 | 6.48 |
| tea | x | | | 0.02 | 16.45 | 15.37 | 4.11 |
| rice | s | | | 0.31 | 30.79 | 25.37 | 15.27 |
| HAILAND | 1964-87 | 5.27 | 1.90 | | | | |
| maize | x | | | 0.10 | 31.38 | 15.91 | 21.92 |
| rice | x | | | 0.27 | 24.88 | 24.12 | 7.49 |
| rubber | x | | | 0.24 | 22.17 | 19.86 | 6.04 |
| URKEY | 1965-87 | 10.91 | 2.71 | | | | |
| cotton | x | | | 0.09 | 20.84 | 16.85 | 8.77 |
| tobacco | x | | | 0.25 | 21.30 | 10.19 | 18.00 |
| maize | s | | | 0.13 | 17.80 | 16.23 | 5.20 |
| oranges | s | | | -0.13 | 14.63 | 9.85 | 7.52 |
| rice | s | | | -0.18 | 26.61 | 25.96 | 13.94 |
| wheat | s | | | 0.16 | 16.65 | 17.23 | 10.05 |
| iron ore | mm | | | 0.11 | 13.77 | 11.45 | 11.98 |
| RGENTINA | 1964-86 | 28.53 | 3.66 | | | | |
| beef | x | | | -0.07 | 18.50 | 16.51 | 9.84 |
| maize | x | | | -0.04 | 28.16 | 16.20 | 20.36 |
| sorghum | x | | | -0.10 | 39.55 | 14.65 | 34.36 |
| wheat | x | | | -0.33 | 30.60 | 16.77 | 26.22 |
| cotton | s | | | 0.15 | 29.32 | 17.09 | 26.34 |
| rice | s | | | 0.19 | 18.52 | 24.63 | 19.67 |
| sugar | s | | | 0.46 | 36.05 | 31.91 | 11.86 |
| RAZIL | 1966-86 | 8.30 | 3.61 | | | | |
| cocoa | x | | | 0.02 | 24.13 | 25.00 | 10.96 |
| coffee | x | | | -0.30 | 21.51 | 22.17 | 35.83 |
| cotton | x | | | 0.52 | 22.19 | 17.64 | 15.17 |
| soybeans | x | | | 0.21 | 30.78 | 19.23 | 20.19 |
| sugar | x | | | 0.15 | 33.35 | 32.77 | 5.76 |
| tobacco | x | | | -0.04 | 14.89 | 10.06 | 8.40 |
| beef | s | | | 0.17 | 16.54 | 16.36 | 6.94 |
| maize | s | | | 0.01 | 15.76 | 16.93 | 10.35 |
| rice | s | | | 0.22 | 26.91 | 25.74 | 12.18 |
| wheat | s | | | 0.39 | 40.97 | 17.39 | 33.85 |
| bauxite | mm | | | 0.00 | 27.26 | 16.91 | 19.91 |
| iron ore | mm | | | 0.36 | 21.39 | 11.29 | 13.42 |
| sphate rock | mm | | | -0.04 | 30.60 | 28.98 | 18.69 |
| HILE | 1964-86 | 13.21 | 6.60 | | | | |
| beef | s | | | 0.36 | 14.11 | 16.51 | 14.86 |
| maize | s | | | 0.18 | 28.80 | 16.20 | 25.58 |
| rice | s | | | 0.09 | 28.05 | 24.63 | 34.06 |
| wheat | s | | | 0.14 | 18.02 | 16.77 | 19.50 |
| copper | mm | | | 0.16 | 22.05 | 22.30 | 7.20 |
| iron ore | mm | | | -0.34 | 23.08 | 10.81 | 15.90 |
| OLOMBIA | 1964-86 | 6.68 | 1.63 | | | | |
| banana | x | | | -0.29 | 9.18 | 8.83 | 6.33 |
| coffee | x | | | 0.19 | 24.98 | 21.70 | 9.34 |
| cotton | x | | | 0.46 | 34.18 | 17.09 | 26.96 |
| beef | s | | | 0.56 | 17.66 | 16.51 | 5.71 |
| maize | s | | | 0.28 | 11.94 | 16.20 | 6.45 |
| rice | s | | | 0.25 | 27.48 | 24.63 | 11.26 |
| sugar | s | | | 0.21 | 34.85 | 31.91 | 6.94 |
| wheat | s | | | 0.16 | 32.86 | 16.77 | 23.23 |
| iron ore | mm | | | -0.53 | 24.14 | 24.04 | 10.81 |
| OSTA RICA | 1964-87 | 13.20 | 3.52 | | | | |
| banana | x | | | 0.16 | 11.24 | 8.70 | 7.10 |
| beef | x | | | 0.30 | 18.77 | 16.29 | 11.67 |
| cocoa | x | | | 0.35 | 42.52 | 24.85 | 29.37 |
| coffee | x | | | 0.33 | 26.35 | 25.72 | 11.35 |
| sugar | x | | | 0.20 | 30.52 | 31.63 | 5.31 |

| Country/ Commodity | Period/ Type | CV of the real exchange rate | CV of GNP | Correlation between project shock and GNP | CV of project shock | CV of world price | CV of production |
|---|---|---|---|---|---|---|---|
| GUATEMALA | 1964-86 | 6.99 | 2.23 | | | | |
| banana | x | | | 0.19 | 11.93 | 8.88 | |
| coffee | x | | | 0.52 | 24.84 | 21.70 | |
| cotton | x | | | 0.67 | 27.84 | 17.09 | 2 |
| sugar | x | | | 0.15 | 34.78 | 31.91 | 1 |
| maize | s | | | -0.09 | 16.70 | 16.20 | |
| MEXICO | 1964-86 | 11.02 | 3.38 | | | | |
| banana | s | | | 0.18 | 15.56 | 8.88 | 1 |
| beef | s | | | 0.04 | 15.40 | 16.51 | |
| maize | s | | | 0.25 | 20.04 | 16.20 | 1 |
| sorghum | s | | | 0.28 | 21.14 | 14.65 | 1 |
| wheat | s | | | 0.27 | 23.43 | 16.77 | 1 |
| iron ore | mm | | | 0.12 | 16.96 | 10.81 | 1 |
| lead | mm | | | 0.30 | 29.24 | 25.83 | 1 |

Note: (1) The coefficient of variation of a variable is approximated by the standard deviation of the logarithm of the variable.
(2) The correlation between project shock and GNP as listed here is the correlation between the logarithms of the project shock and GNP.

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