Growth and Risk: Methodology and Micro Evidence

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How exposure to risk affects economic growth is a key issue in development. This article quantifies both the ex ante and ex post effects of risk using long-running panel data for rural households in Zimbabwe. It proposes a simulation-based econometric methodology to estimate the structural form of a micro model of household investment decisions under risk. The key finding is that risk substantially reduces growth in this particular setting: the mean capital stock in the sample is (in expectation) 46 percent lower than in the absence of risk. About two-thirds of the impact of risk is due to the ex ante effect (that is, the behavioral response to risk), which is usually not taken into account in policy design. These results suggest that policy interventions that reduce exposure to shocks or that help households manage risk could be much more effective than is commonly thought. JEL Codes: D10, D91, C51, O12

Growth and risk are central issues in development. While the two phenomena are usually studied in isolation, it is often suggested that they are closely linked. For example, Collier and Gunning (1999a) use microeconomic evidence to show that the responses of agents to risk are an important part of the explanation for Africa’s poor growth performance. Risk management involves changes in the choice of activities: households may choose low-risk activities or portfolios of activities that are well diversified. Diversification is, of course, costly: the household forgoes the gains from specialization. In itself this is a level effect that does not necessarily affect growth. However, level effects easily translate into growth rate effects—for example, when there are indivisibilities in investment and imperfections in credit markets, typical for many rural areas in Africa.

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In addition to managing risk through activity choice, households use various risk-coping strategies. In the absence of well functioning credit and insurance markets, self-insurance (saving and lack of saving in response to income shocks to smooth consumption) and informal social security institutions are used instead. Consumption smoothing typically involves changes in food stores, livestock, or both. These assets are also subject to substantial risk (theft, vermin, spoilage, livestock illnesses), making consumption smoothing less effective as a risk-coping strategy.

There is growing evidence on the cost of such risk management and coping mechanisms: they lower income, perpetuate poverty, and cause the effects of shocks to persist over long periods (Rosenzweig and Binswanger 1993; Morduch 1999; Dercon 2003, 2004; Jalan and Ravallion 2005). The significance of growth-reducing responses to risk is now widely recognized, but neither the theoretical nor the empirical literature provides much guidance for quantifying the effect of risk on growth.

Much of growth theory is, of course, deterministic, so the issue cannot be addressed. Interest in growth under uncertainty has recently been revived (for example, Binder and Pesaran 1999; de Hek 1999; after early contributions such as Levhari and Srinivasan 1969), but these contributions typically examine special cases. For example, risk has no ex post effect in the Levhari–Srinivasan model and no ex ante effect in the Binder–Pesaran model.1

The empirical literature also shows a growing interest in the effect of risk on growth, at both the macro and the micro levels (Ramey and Ramey 1995; Guillaumont and Chauvet 2001; Jalan and Ravallion 2001). Most of these studies use a reduced-form specification for the income-generating process. There are a few examples of structural models. For example, Rosenzweig and Wolpin (1993), who analyzed optimal accumulation under risk in Indian villages, concluded that introducing actuarially fair insurance in these villages would not raise welfare because farmers are already adequately protected through informal insurance. Formal insurance therefore offers no benefits and (in their model) does not lower the cost of risk coping either.2 As a result, Rosenzweig and Wolpin find no effect on investment when risk is reduced.

In this article an intertemporal optimization model is estimated for a rural household using a unique long-running panel dataset for rural households in Zimbabwe that were initially part of a government land reform and resettlement program. These households make little use of financial assets and informal insurance, and their investment takes the form largely of building up their own livestock herd. The analysis of their behavior focuses on consumption


2. Profits are net of the implicit premium paid for informal insurance, but this premium is not known. Hence, if farmers were to switch from informal to formal insurance, the constant term in the profits function is not adjusted: farmers would implicitly continue to pay for informal insurance (Rosenzweig and Wolpin 1993).
smoothing as the key risk-coping strategy. In this respect the model is similar to that of Deaton (1991). However, in Deaton’s model households have no incentive to save in the absence of risk, and they have access to a safe asset. The model used here to describe the Zimbabwean farmers differs in both respects. First, it exhibits conditional convergence in the absence of risk. Households start very poor, with asset holdings far below the steady-state level. As a result, they have an incentive to accumulate capital (livestock). This process of growth provides a benchmark for addressing the growth and risk question because accumulation under risk can be compared with this risk-free counterfactual. Second, households are exposed to shocks that affect both livestock and the income from agriculture where livestock is used as an input. Hence, these farmers have no access to a safe asset.

Since the costs and benefits of consumption smoothing are explicitly modeled, the impact of actuarially fair insurance or, equivalently, the effect of risk on growth can be assessed. Whether that effect is strong or weak and positive or negative is an empirical matter: the model can in principle generate widely different results. In particular, whether risk increases or reduces households’ propensity to accumulate assets is not implied by the specification. It depends on the nature of risk (notably the relative importance of income and asset shocks) and on how risk-averse households are. These issues are not resolved a priori but are left to the estimation phase. Using the estimated micro growth model to assess the effect of risk on growth yields a very strong negative effect. Under risk the expected value of the capital stock at the end of a 50-year simulation period is 46 percent lower than it would have been in the counterfactual risk-free case.

Risk not only reduces capital accumulation and hence growth; it also has a negative effect on household welfare. The results suggest that policy measures that reduce the risk exposure of these households or that offer more efficient risk coping (for example, through insurance) would have powerful effects not only on growth but also on household welfare.

I. EX ANTE AND EX POST EFFECTS OF RISK

A household’s economic decisions (for example, on savings) are affected by risk in two ways: through the household’s experience of shocks and through its

3. Dercon (1996) extends Deaton’s model by making agricultural income depend on the allocation of labor between two crops, one risky, the other risk-free. In this model removing risk leads to full specialization, but the effect on growth cannot be analyzed. As in Deaton’s model, there is no incentive for accumulation in the absence of risk.

4. Dercon (2005) stresses that models of consumption smoothing (e.g., Deaton 1991) often assume that agents have access to a safe asset. This overstates the effectiveness of consumption smoothing as a risk-coping strategy.

5. Since the model has a steady state, growth should be understood as transitional dynamics.
perception of the distribution of the shocks it faces. It is useful to formalize this distinction.

Suppose household investment decisions can be summarized as:

\[ k_{t+1} = \varphi(k_t; s_t; \sigma) \]  

where \( k \) denotes the household’s capital stock, \( s \) a shock (with expected value \( E_s = 1 \)), and \( \sigma \) a parameter characterizing the distribution from which \( s \) is drawn. At this stage the definition of \( \sigma \) is irrelevant, except that an increase in \( \sigma \) can be interpreted as an increase in risk and that \( \sigma = 0 \) denotes the risk-free case. In general, risk affects \( k_{t+1} \) (and thereby growth in the sense of transitional dynamics) not just through \( s \) but also through \( \sigma \). Changes in \( \sigma \) will in general change the household’s behavior: the household will choose a different value of \( k_{t+1} \) for the same values of \( k_t \) and the current shock \( s_t \). This is the ex ante effect of risk. An example is the effect on investment behavior of the possibility of civil war breaking out. The household has not yet been exposed to a shock, but it knows that peace is precarious, so its assessment of the likelihood of violent conflict will have a powerful effect on its investment decisions. Hence, the ex ante effect results from the household’s view of the world: two households that differ in their perception of the risks they face but that are identical in all other respects will in general make different investment decisions. By contrast, the ex post effect measures the impact of the shocks themselves. The effect of risk can be decomposed into ex ante and ex post components.

Applying equation (1) repeatedly leads to

\[ k_{t+T} = g(k_t; s_t, s_{t+1}, \ldots, s_{t+T-1}; \sigma) \]  

for some suitably defined function \( g() \). Taking expectations

\[ E_t k_{t+T} = E_t g(k_t; s_t, s_{t+1}, \ldots, s_{t+T-1}; \sigma) \]

\[ = g(k_t; 1, 1, \ldots, 1; \sigma) - [g(k_t; 1, 1, \ldots, 1; \sigma) - E_t g(k_t; s_t, s_{t+1}, \ldots, s_{t+T-1}; \sigma)] \]

\[ = g(k_t; 1, 1, \ldots, 1; \sigma) - [\text{ex post effect}] \]

\[ = g(k_t; 1, 1, \ldots, 1; 0) - [g(k_t; 1, 1, \ldots, 1; 0) - g(k_t; 1, 1, \ldots, 1; \sigma)] \]

\[ = [\text{ex ante effect}] - [\text{ex post effect}] \]

hence

\[ g(k_t; 1, 1, \ldots, 1; 0) - E_t k_{t+T} = [\text{ex ante effect}] + [\text{ex post effect}]. \]

Here \( g(k_t; 1, 1, \ldots, 1; 0) \) is the value of \( k_{t+T} \) that the household would attain in a risk-free world (with \( \sigma = 0 \)); \( g(k_t; 1, 1, \ldots, 1; \sigma) \) is the hypothetical value
reached if the household expects shocks drawn from a distribution with positive $\sigma$ but in fact experiences no shocks ($s = 1$ in all periods). Note from equation (3) that the two effects are defined in such a way that a positive value implies that growth is reduced. In section V equation (3) is applied in the analysis of risk in Zimbabwe.

That shocks can make the path of $k$ volatile is obvious, but that risk affects the expectation $E_k$ is not. Indeed, there is no presumption in theory about the sign (let alone the size) of the ex ante and ex post effects. The effect of risk on growth is therefore an empirical issue.

Usually in empirical research equation (1) is estimated by regressing $k_{t+T}$ (or some other proxy for growth) on various controls (country characteristics in macro growth regressions, household characteristics in micro studies), measures of $s$, and, possibly, measures of $\sigma$. Two cases can arise, depending on data availability. If $\sigma$ does not vary in the sample (for example, because all households face the same rainfall risk, $\sigma = \overline{\sigma}$), without further identifying restrictions the effect of changes in $\sigma$ (the ex ante effect) can obviously not be identified, and only $k_{t+1} = \varphi(k_t, s_t; \overline{\sigma})$ can be estimated. The estimated function can then be used to measure the ex post effect (by imposing $s_t = 1$), but the total effect of risk cannot be identified. By contrast, when there is variation in risk (for example, in cross-country growth regressions when country-specific measures of climatic risk are available), both the ex ante and ex post effects can in principle be identified.6

In the sample all households face the same risk, so there is no variation in $\sigma$. A reduced-form estimation of equation (1) would therefore at best produce an estimate of the ex post effect. To identify the ex ante effect as well, the model is estimated in its structural form rather than as a reduced form. The assumption that household behavior is generated by intertemporal optimization makes it possible to identify the effect of changes in $\sigma$.

The ex post effect of risk is defined in terms of changes in the expected outcome $E(k_{t+T})$ not in terms of the effect of a particular realization $s_t$ (or series of shocks $s_t, s_{t+1}, \ldots$). Some studies investigate the impact of such realizations on the outcome $k_{t+T}$ rather than on its expected value.7 For example, Dercon and Krishnan (2000) study the effect of illnesses on household consumption, and Alderman, Hoddinott, and Kinsey (2004) investigate the persistent effects of a drought in Zimbabwe on the health of children. Similarly, the literature on trade shocks (for example, Collier and Gunning 1999b) studies the impact (and its persistence) of changes in terms of trade. By contrast, this article focuses on the impact of changes in risk (in the sense of mean-preserving

6. For example, Dehn (2000) includes both actual trade shocks and a country-specific measure of the distribution of trade shocks in a growth regression. Ramey and Ramey (1995) estimate a cross-country growth regression in which the standard deviation of the error term is country-specific and affects growth.

7. Such studies work in the tradition of Knightian uncertainty, whereas the approach here assumes that shocks are frequent and that agents know their distribution.
changes in the distributions of shocks) rather than on the impact of particular shocks.

II. THE MODEL

There is a single good used for consumption as a store of value and as a productive asset. Agents maximize expected utility over an infinite horizon. Each household solves:

\[
\max_{\{c_t, k_{t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t)
\]

subject to

\[
c_t = s_1 t \lambda a f(k_t) + s_2 t (1 - \delta) k_t - k_{t+1}
\]

for \(t = 0, 1, 2, \ldots\) and \(k_0, s_{10}, s_{20}\) given

where \(c\) denotes consumption, \(k\) the capital stock, \(a\) a household-specific total factor productivity, \(u\) the instantaneous utility function, \(f\) the production function, \(\beta\) a discount factor, \(\delta\) the depreciation rate, \(\lambda\) the relative price of output (in terms of the asset), and \(t\) time. It is assumed that \(u\) and \(f\) are strictly concave and that \(0 < \beta < 1\). Note that \(\beta\) and \(\delta\) are constant.

The household faces both income (\(s_1\)) and asset (\(s_2\)) shocks. When the household decides on \(c_t\) and \(k_{t+1}\), both \(k_t\) and the realizations (\(s_{1t}, s_{2t}\)) are known. Future shocks are, of course, unknown, but the household knows the distributions of these shocks; these distributions are assumed to be independent over time. (Note that this assumption of rational expectations excludes learning processes whereby the household adjusts its estimates of the distribution of shocks.)

The application here allows for two types of heterogeneity: households differ in their initial capital stock, \(k\), and in productivity, \(a\).

Some of the limitations of the stochastic Ramsey model, equation (4), should be noted. First, each household is modeled as a Robinson Crusoe economy, which is clearly restrictive. In particular, households are not linked through credit transactions or risk pooling. Descriptive evidence suggests that there are indeed few credit transactions in this sample, but informal risk-pooling arrangements do exist. Modeling such existing arrangements is a challenge for

8. There are well known critiques of expected utility. Recursive utility (Epstein and Zin 1991) is an attractive alternative specification, and the recursive modeling and estimation strategy used here (based on the Bellman equation) lends itself to this alternative. Future work should investigate whether the results on growth and risk are sensitive to changes from the expected utility framework.

9. Total factor productivity is time-invariant from the household’s point of view. In fact, it changes, for example, with household size. Such changes are modeled as part of the shocks to which the household is exposed.
future research. This analysis proceeds as though there are no risk-pooling arrangements so that consumption smoothing is the only risk-coping strategy available to households. This is clearly restrictive, and objections might be raised that assuming risk pooling necessarily overstates the effect of risk on growth. This is considered in section IV.

Second, in the model the capital stock used in production is the only asset available to the household. For the Zimbabwe application this is reasonable: eligibility rules for the resettlement program ruled out diversifying into nonagricultural activities, and the households have very few assets other than livestock. Obviously, it is desirable to allow for multiple assets to model multiple crops or financial assets. However, allowing for multiple assets in agricultural production greatly increases the computational burden of estimating and simulating the model.\(^\text{10}\) Introducing financial assets is much less problematic, provided the agricultural asset (livestock) is tradable, because the policy function continues to have a single argument: wealth at hand.

Third, the relative price, \(\lambda\), (for which there are no observations) is treated as constant over time. This implies that price-related risk is captured in \(s_1\).

The Ramsey specification does not imply that the ex ante effect is either positive or negative. A well known result (for example, Newbery and Stiglitz 1981) is that in a two-period model with a safe asset, strict convexity (concavity) of the marginal utility function implies a positive (negative) effect of risk on investment.\(^\text{11}\) However, the sign of the effect depends not only on the utility function but also on the nature of shocks. This may be illustrated by considering a two-period version of the model:

\[
\max_{k_2} u(c_1) + \beta E u(c_2) = u(s_{11}\alpha(k_1) + s_{21}(1 - \delta)k_1 - k_2) + \beta E u(s_{12}\alpha(k_2) + s_{22}(1 - \delta)k_2)
\]

(5)

with \(k_1\), \(s_{11}\), \(s_{21}\) given. Assume unitary relative risk aversion: \(u(c) = \ln c\). If risk

10. Rosenzweig and Wolpin (1993) in a somewhat similar model reduce this burden by imposing indivisibilities (for example, by allowing for only three levels of cattle ownership: 0, 1, and 2). This seems very restrictive.

11. Consider the model

\[
\max_{k_2} u(c_1) + \beta E u(c_2) = u(s_{11}y - k_2) + \beta E u(s_{12}y + (1 + r)k)
\]

where \(s_{11}\) is known, \(y\) is the mean of nonasset income, and \(r\) the return on the safe asset \(k\). The first-order condition is

\[
u'(c_1) = (1 + r)\beta E u'(c_2).
\]

Clearly, if \(u'(c_2)\) is strictly convex in \(s_{12}\), an increase in risk would increase the right side of the condition, and an increase in \(k_2\) would be required to maintain equilibrium. Hence, in this model the effect of risk on savings is positive for a convex marginal utility function.
affects only income (that is, $s_{2t} = 1$), the first-order condition is

$$u'(c_1) = \beta E \frac{s_{12} f''(k_2) + (1 - \delta)}{s_{12} f(k_2) + (1 - \delta) k_2}.$$  

(6)

The concavity of $f$ implies that the expression after the expectation sign is strictly convex in $s_{12}$. Hence, an increase in risk (that is, a mean-preserving spread applied to the distribution of $s_{12}$) raises the right-hand side of the condition. Equilibrium is restored through an increase in the optimal value of $k_2$. It follows that the effect of risk on investment is positive in this case. Conversely, if risk applies only to assets (so that $s_{12} = 1$), an increase in risk reduces the optimal value of $k_2$.

In a multiperiod model asset shocks are more important in the sense that their effect is permanent, whereas income shocks have no persistence. This makes a negative effect of risk on growth more likely.) This example indicates that the relative importance of the two types of shocks, an empirical matter, is another determinant of the sign of the effect of risk on growth in this model.

In the Zimbabwe study the effect of risk on growth is dominated by the ex ante effect. Again, this is not an implication of the Ramsey model. For example, in the special case with log utility, $f(k) = k^\alpha$, and $\delta = 1$ there is no ex ante effect, whereas there is an ex post effect.

III. DATA

In the early 1980s the government of Zimbabwe undertook a land reform program involving the resettlement of peasant farmers and landless laborers on land formerly owned by commercial white farmers. To be eligible for resettlement household heads had to be married (or widowed), not in formal employment, and not younger than 18 or older than 55. They were randomly assigned to resettlement schemes and had to renounce any claims to land elsewhere. Initial landholdings were identical: each settler was assigned 5 hectares of arable land.

Resettled households could engage only in farming, an important restriction that ruled out risk coping through diversification into nonagricultural activities. Since all households received the same area of arable land and land cannot be sold (and there is virtually no land rental), households are basically identical in terms of landholding. However, after 20 years of heterogeneity in terms of demographic growth, they differ markedly in land-to-person ratios. They also

12. These results follow from application of Jensen’s inequality to the first-order condition.
13. This is related to Dercon’s (2005) simulation results showing that asset risk greatly reduces the effectiveness of consumption smoothing compared with the case modeled by Deaton (1992), where risk affects income but households have access to a riskless asset.
14. This section is based on Gunning and others (2000) and Hoogeveen (2001).
differ in terms of total factor productivity: there are very large yield differences, controlling for farm inputs. Some are simply much better farmers than others. There are also very large differences in livestock ownership. Livestock is the most important asset in this rural economy.

The key risk in these village economies is rainfall. This risk is, of course, highly covariant, limiting the scope for local risk pooling. While there is some informal insurance in the survey villages there is no formal credit or insurance, and the dominant risk-coping strategy is consumption smoothing through the use of livestock. Herds are built up after a good harvest, while in bad times cattle is used for own consumption, either directly or by selling cattle to finance the purchase of maize, the staple crop.\textsuperscript{15}

In 1983/84 Kinsey surveyed a sample of about 400 resettled households. The sampling frame consisted of all resettlement schemes established in the first two years of the program. The sample was restricted to the three most important natural regions or agro-climatic zones, designated NR II (moderately high agricultural potential), NR III (moderate potential), and NR IV (restricted potential). One scheme was selected randomly for each zone: Mupfurudzi in Mashonaland Central (north of the capital Harare) for NR II, Sengezi in Mashonaland East (south east of Harare) for NR III, and Mutanda in Manicaland (also south east of Harare) for NR IV. Stratified sampling was then used to select 20 villages within these schemes, and for each selected village in two of the areas a complete census was attempted, while in the third area 10 households were randomly selected from each village.

The households were interviewed first in 1983/84 (shortly after their resettlement), again in 1987, and then annually since 1992. This is the longest running panel dataset in Africa,\textsuperscript{16} spanning a period in which these households’ assets and incomes grew very rapidly, despite exposure to massive shocks, including a severe drought. The questionnaire included questions on crop production, sales, labor hiring, credit, food storage, anthropometrics, and detailed information on livestock ownership.\textsuperscript{17} There are no data on household consumption. Initially the scope of the survey was more limited, and the questions were partly retrospective; for example, the first survey round in 1983/84

\textsuperscript{15} For the purpose of this article this is very fortunate: while rural households in Africa typically engage in a range of nonagricultural activities, the resettled households were restricted to farming in the period considered.

\textsuperscript{16} This article uses only the NR II data that have remarkably little sample attrition. Approximately 90 percent of households interviewed in 1983/84 were re-interviewed in 1997. There is no systematic pattern to the few households that dropped out. Some were inadvertently dropped, a few disintegrated (such as those where all adults died), and a small number were evicted by government officials. What is tracked is the land assigned to the original settlers, not the household itself: the household is retained even if its composition changes. The most important such change is the death of the household head, but even this is rare (Hoogeveen 2001).

\textsuperscript{17} The survey collected data on various types of livestock (oxen, heifers, goats, and the like). These were aggregated using constant market prices following Hoogeveen (2001).
asked about initial livestock holdings at the time of resettlement. Five observations on $k_t$ exist: at the time of resettlement, 1992, 1993, 1996, and 2000. Only two observations on crop income exist: 1993 and 1996. Covariant risk is measured by the log of rainfall for which location-specific time-series data are available.

The empirical study of economic growth is riddled with measurement error problems (Bliss 1999; Carroll 2001). Measurement errors are expected to be less serious in this application for two reasons. First, in contrast to growth regressions, which have to rely on data collected by different institutions, using a micro dataset means that a single method of measurement is used. Second, the estimations can be based on asset (livestock) data rather than income data. While income and expenditure data are notoriously noisy, the importance of cattle in most African societies suggests that the most important component of livestock is measured fairly accurately.

IV. ESTIMATION

The estimation proceeds in two steps. First, the production function and an equation for total factor productivity are estimated. A constant elasticity of substitution production function is assumed in capital and labor, with parameters $\rho$ and $\psi$:

\[
f(k; n) = n \left( 1 + \psi \left( \left( \frac{k}{n} \right)^{-\rho} - 1 \right) \right)^{-1/\rho}
\]

where $n$ is household size. Total factor productivity is assumed to be a function of household size and the highest educational attainment of its adult members at the time of resettlement ($e$):

\[
a = a_0 + a_1 n + a_2 e.
\]

Denote crop income as $y = af$. The function $af$ is estimated using data for two years, 1993 and 1996. Treating productivity $a$ as a household fixed

18. The households in the sample accumulated cattle very rapidly between resettlement and 1992 (Gunning and others 2000). The absence of data for the intervening years is an unfortunate limitation of this dataset. In the estimation the time of resettlement was set at 1980 for all households.


20. In principle, all parameters could be estimated simultaneously. However, production data are available for only two years in the Zimbabwe dataset.

21. The usual objection to direct estimation of the production function—that outputs and inputs are determined simultaneously—does not carry much force here. Since households are exposed to shocks, the optimal use of inputs is continually disturbed.
effect, the parameters $\psi$ and $\rho$ in equation (7) are estimated by nonlinear regression of $y_{96}/y_{93}$ on $f(k_{96})/f(k_{93})$. The parameters of equation (8) are then estimated by regressing $\ln(y_t/f(k_t, n_t; \hat{\psi}, \hat{\rho}))$ on household size and education, allowing for household random effects (table 1).22

Productivity is decreasing in household size and increasing in education, but these effects are not significant. The estimated value of $\rho$ implies a substitution elasticity—equal to $1/(1 + \rho)$—of about 2. It does not differ significantly from 0, that is, from the Cobb–Douglas case with unitary substitution elasticity. Instead of imposing the Cobb–Douglas value ($\rho = 0$), the point estimate is retained.

Given the parameters of the function, $af$, the remaining parameters are then estimated. The model of equation (4) is extended to allow for Hicks-neutral technical progress at a constant rate, $\tau$. Define $\bar{c}_t = c_t(1 + \tau)^{-\tau}$ and $\bar{a} = \lambda a(1 + \tau)^{-\tau}$. (Recall that $\lambda$ denotes the fixed relative price of output in terms of the asset.) The revised model becomes:

$$\max_{\{c_t, k_{t+1}\}} E_0 \sum_{t=0}^{\infty} (\beta(1 + \tau)^{\gamma})^{t\bar{c}_t^{\gamma}}$$

subject to

$$(1 + \tau) k_{t+1} = s_{1t} \bar{a} f(k_t) + s_{2t} (1 - \delta) k_t - \bar{c}_t$$

for $t = 0, 1, 2, \ldots$ and $k_0, s_{10}, s_{20}$ given.

The utility function (common to all households) is assumed to be of the constant relative risk-aversion type, $u(c) = c^\gamma$ for $\gamma < 1$ and $u(c) = \ln c$ for $\gamma = 0$ (unitary relative risk aversion). Discount rates are identical across households.

22. The results are virtually the same if no random effect is included. In that case the estimate for $\psi$ is 0.5340 and for $\rho$ is –0.4713. Similarly, specifying $a$ as a log-linear function of education and household size does not lead to substantially different results.
Both idiosyncratic and covariant risk are allowed for:

\[
\ln s_{it} = \pi r_t + \varepsilon_{it}\quad \text{for } i = 1, 2
\]

where \( r \) measures covariant risk, \( \varepsilon_i \) idiosyncratic risk, and \( \pi \) is a parameter. Risks are assumed to be independent over time, but correlation between \( \varepsilon_{1t} \) and \( \varepsilon_{2t} \) is allowed for. In this application \( (\varepsilon_1, \varepsilon_2) \) are jointly normally distributed (with mean 0) and independent of \( r \), which is also normal.

Rainfall data exist for the covariant risk, \( r \), but no data exist for the idiosyncratic shocks, so this is left to the estimation procedure.\(^{23}\) Demographic change (birth, death, and disability) for Zimbabwean farmers is largely unplanned and is thus incorporated into the idiosyncratic part of the shocks. Rational expectations are assumed, that is, households know the distributions of the shocks.

There now are nine parameters to estimate: \( \gamma \), the parameter of the utility function; \( \beta \), the discount factor; \( \lambda \), the relative price; \( \delta \), the rate of depreciation; \( \pi \), the rainfall elasticity; \( (\sigma_1, \sigma_{12}, \sigma_2) \), the parameters of the distribution of the idiosyncratic shocks; and \( \tau \), the rate of technical progress. (Clearly only the product \( a\lambda \) can be estimated. \( a \) is identified by setting the average value of \( a \) equal to 5.)

These parameters are estimated by simulated pseudo maximum likelihood.\(^{24}\) First, a set of parameter values, a vector \( \theta \) is chosen. Given these parameters, the optimization problem is solved for each household \( h \). This gives a household-specific policy function, \( \varphi(w) \), which indicates optimal investment as a function of wealth on hand, \( w \), as determined by the capital stock and shocks in the current period: \( k_{t+1} = \varphi(w_t) \), where \( w_t = s_{1t}\tilde{a}f(k) + s_{2t}(1-\delta)k_t \). The appendix describes how this function can be approximated.

This policy function can now be used in simulation experiments. Given an initial value \( k_t \) and randomly generated shocks \( s_{1t} \) and \( s_{2t} \), the optimal value of \( k_{t+1} \) can be calculated. This method is used to generate paths of accumulation over the time between dates for which observations exist: 1980, 1992, 1993, 1996, and 2000. Conditional on rainfall (the shock component common to households), the changes in capital stocks between observation dates are statistically independent across households and time. A large number of paths are generated by drawing new values for the household idiosyncratic shocks \( s_{1t} \) and \( s_{2t} \).

Interval-specific means and variances are then calculated. Since a ragged panel is used, the distribution of changes in \( k \) is assumed to be log-normal, which is sufficient to calculate the likelihood \( L(\theta) \) of the observations for the given parameter vector \( \theta \). The parameter vector is then changed, using hill

\(^{23}\) Estimate for separate elasticities \( \pi_1 \) and \( \pi_2 \) were attempted, but the results suggested a high degree of correlation. \( \pi_1 = \pi_2 = \pi \) was therefore imposed.

\(^{24}\) See, for example, section 3.2 of Gouriéroux and Montfort (1996).
climbing to maximize the likelihood with respect to the parameters. This provides pseudo maximum likelihood estimates of the nine parameters (table 2).

The estimated value of $\gamma$ is very close to zero, implying log utility and a unitary degree of relative risk aversion. The estimate of $\beta$ suggests a high degree of impatience: a discount rate of 34 percent. The depreciation rate, $\delta$, should be interpreted as a net rate, reflecting not just the aging and death of animals but also livestock births. The (co)variance parameters of the idiosyncratic shocks are highly significant. The estimates imply that the standard deviation of $\ln s_1$ is equal to 0.27 and that of $\ln s_2$ 0.28. The correlation between the two types of shocks is 0.86. These estimates imply a very high level of idiosyncratic risk. For example, the probability of a household experiencing a shock of at least 10 percent of its income ($s_1 > 1.1$ or $s_1 < 0.9$) in any year is 71 percent. The rate of technical progress cannot be precisely estimated. An earlier estimate using a different methodology (Gunning and others 2000) was higher but within the 95 percent confidence interval of the point estimate here (slightly below 1 percent a year). The estimated value of $\pi$ is very significant but remarkably low.25

In this model every household is essentially a single-agent economy. In particular, households do not pool idiosyncratic risk. This is clearly a very strong assumption that might seem to cause the results to overstate the effect of growth on risk. This is not the case. Consider a proportional risk-pooling arrangement that provides partial insurance, presenting an agent with a shock $\xi s t (0 < \xi < 1)$ when a shock $s$ occurs. By ignoring the existence of such an arrangement, the estimation procedure here understates the extent of risk. It will in fact produce an estimate of $\sigma \xi$ rather than of $\sigma$: the partial insurance

25. This is a common empirical finding; see, for example, Rosenzweig and Binswanger (1993).
Figure 1. Growth and Risk: Capital Accumulation for a Selected Household

Note: The “No risk” path corresponds to \( g(k_0,1,\ldots,1;0) \), the “No ex post risk” path corresponds to \( g(k_0,1,\ldots,1;\sigma) \), and the “Average under risk” path corresponds to \( E_0 k_t \).

Source: Authors’ analysis based on Zimbabwe survey data.

The estimated model is used to determine the effect of risk on growth. Four paths of the real value of the capital stock (scaled by the household’s labor force) are followed over a 50-year period, starting at \( t = 0 \) from the household’s actual starting position (figure 1).\(^{27}\)

\(^{26}\) Going slightly further, partial insurance can be tested for by replacing shock \( s \) with insurance-modified shock \( A + Bs \), where \( -A \) can be interpreted as the insurance premium and \( B \) as the degree of risk mitigation. Note that with log-normally distributed shocks \( s \) and \( A, B \neq 0 \), \( A + Bs \) is not log-normally distributed, so the model would be misspecified for this type of risk pooling. If risk sharing is important, a significantly improved fit could be obtained by allowing \( A \) and \( B \) to vary. The signs of \( A \) and \( B - 1 \) would depend on whether the sample households’ average position is long or short. The unrestricted estimation results give a value of \( A \) that is not significantly different from zero and a value of \( B \) that is not significantly different from 1. Also, the likelihood shows very little improvement as a result of dropping the restrictions \( A = 0, B = 1 \). In this sample the weak test of “no risk pooling” is passed. This may reflect the particular nature of the sample: the resettlement farmers came from different parts of the country and therefore had no previous ties.

\(^{27}\) This household has values of total factor productivity and initial capital close to the median in the sample. Calculating means over households yields similar results. The capital stock is scaled by dividing it by the labor force times the factor \( (1 + \tau)^T \) so that (in these units) the capital stock converges to a constant level in the deterministic case.
The sample path is one possible growth path, defined by a particular series of 50 randomly drawn shocks, one for each year. The point to note is how volatile this path is: the capital stock (livestock) frequently changes by as much as 50 percent in one or two years.\textsuperscript{28} Clearly, time-series data for part of this growth path would make it very difficult to say something about the underlying growth process.

The model was used to generate 100,000 growth paths. For each year the expected value of the household’s capital stock was then calculated as the mean over these paths. The time path of this mean is shown in figure 1 as $E_0 k_T$ (for $T = 1, \ldots, 50$). The averaging procedure, of course, removes the volatility. The path shows how much livestock the household would expect to obtain at future dates, from the standpoint of $t = 0$. Since the household starts out very poor (with $k_0 = 0.56$), it initially grows very rapidly (in expectation), at some 9 percent a year in the first 10 years.

Now consider the effect of risk on growth. The distribution of shocks is initially kept unchanged, but instead of drawing shocks $s$ from this distribution the household is presented with $s = Es = 1$ in each period. Hence, the household faces the same risk as before but, as it happens, never experiences a shock. This is the path of $g(k_0; 1, \ldots, 1; \sigma)$, using the notation of section II. The vertical difference between this curve and path $E_0 k_T$ is the ex post effect. Next, the path of $k$ is calculated in the absence of risk by taking the (co)variances of the shocks to 0 while, as before, presenting the household with $s = Es = 1$ in each period. Clearly, this implies that the household solves a nonstochastic optimization problem: it knows that it faces no risk and indeed experiences no shocks at any point in time. This yields the path of $g(k_0; 1, \ldots, 1; 0)$. By construction the vertical distance between this curve and the path $g(k_0; 1, \ldots, 1; \sigma)$ measures the ex ante effect.

The effect of risk is massive: the household would have accumulated much more capital in the absence of risk. For this household the total effect of risk is dominated by the ex ante effect (figure 1).

These results also apply to the sample households as a group. In the sample risk reduces the expected long-run value of the capital stock, $E_0 k_{50}$, 46 percent below the steady-state value, $k^*$, in the deterministic risk-free case: $E_0 k_{50} = 0.54 k^*$. This is a striking result. Risk not only makes growth very volatile (illustrated vividly by the sample path), it also greatly lowers growth on average. Two-thirds of this reduction is accounted for by the ex ante effect, the rest by the ex post effect—also a remarkable result. Much of the empirical literature (e.g., Ravallion 1988; Dercon and Krishnan 2000; Dercon 2004) implicitly assumes that the actual shocks are an adequate measure of the effect of risk. But they are not in the case of Zimbabwean

\textsuperscript{28} These simulation results are confirmed by the data, which show large shocks in the $k$ time-series. A simple regression of $\ln k$ on its lagged value gives a residual standard error of 0.3. This implies that changes of 50 percent are indeed quite common.
households: much of the expected impact is internalized as different investment decisions. Chronic poverty is often diagnosed as the result of poor endowments, as opposed to transient poverty, which is seen as the result of risk. The calculations here show that risk has a very substantial effect on mean consumption as well. In that sense risk is a structural determinant of chronic poverty.

The risk-free case can be interpreted as what would happen if actuarially fair insurance were introduced. The sum of the ex ante and ex post effects then measures the effect of such insurance on capital accumulation. Figure 1 would look very similar if welfare had been plotted; in particular, the ranking of the three cases is the same: risk causes a substantial welfare loss, and much of this loss is reflected in the ex ante effect. The implication is that policies designed to reduce the exposure of households to risk or to help households to cope with risk improve welfare. In particular, these households would gain substantially from actuarially fair insurance.

VI. CONCLUSION

Empirical work using micro datasets for rural households has uncovered much evidence of the impact of risk on income levels, investment, and portfolio decisions (for example, crop diversification). While the effect of risk on growth is recognized as a key issue in development, micro studies have seldom quantified it. This quantification is the central objective here.

This article makes three contributions. First, it proposes a framework for analyzing the effect of risk on growth, distinguishing between the ex ante and ex post effects of shocks. Second, it estimates a stochastic growth model in its structural form using simulation methods. If all households face the same risks (as assumed here), the effect of risk on growth cannot be identified from a reduced-form regression. Moreover, using simulation methods to estimate growth models eliminates the need for the simplifications usually adopted in applied work to make the estimation problem tractable (for example, linearization around the steady state).

Third, turning from the methodology to the micro evidence, the application here shows that for a sample of rural households in Zimbabwe (observed for almost a generation) risk has a very substantial effect on capital accumulation (and hence on poverty). The average (across households) expected long-run capital stock is estimated to be 46 percent lower than in the absence of risk. This confirms the suggestion in the literature that self-insurance and other microeconomic responses to risk may substantially reduce growth.

The magnitude of the impact of risk on economic growth in Zimbabwe suggests that policymakers may need to reconsider the balance between interventions that address structural determinants of poverty (for example, raising productivity through education or improvements in farm practices) and interventions that reduce exposure to shocks or help households manage risk. The results here
suggest that the welfare costs of risk can be very high. The potential benefits of policy interventions to reduce exposure to risk or promote insurance or credit may therefore be much greater than previously envisaged.\(^{29}\) Such policies are usually seen as reducing the volatility of household income around a given mean. That risk can massively reduce the mean implies that this perspective (common in the literature on household vulnerability) can be misleading: much of what is classified as structural poverty may in fact reflect households’ exposure to risk.

The design of the land reform program makes the Zimbabwe case special, for example, by severely limiting the scope for diversification and reducing the incentives for investment in education. Extending this work to other countries is therefore an important area for research: to what extent the Zimbabwe results can be generalized remains an unanswered question. Also, the model here involves some stark simplifications. These are intended to be relaxed in future work, notably by increasing the number of assets and allowing for informal risk pooling.

APPENDIX. SOLVING THE STOCHASTIC RAMSEY MODEL

Consider the case where there is no technical progress, so that \(\bar{a}\) is constant. Define wealth on hand, \(w\), as \(w = s_1\bar{a}(k) + s_2(1 - \delta)k\) and shocks as \(s = (s_1, s_2)\). If a solution exists, the model can be written in recursive form as the stationary Bellman equation:

\[
V(w(k, s)) = \max_{\bar{k}} u(w(k, s) - \bar{k}) + \beta EV(w(\bar{k}, \bar{s}))
\]

with associated policy function

\[
\varphi(w(k, s)) = \arg\max_{\bar{k}} u(w(k, s) - \bar{k}) + \beta EV(w(\bar{k}, \bar{s}))
\]

where \(k\) denotes the capital stock at the beginning of the current period and \(\bar{k}\) at the end, and \(s\) denotes current shocks and \(\bar{s}\) future ones. Equation (A-1) applies to every period, so time subscripts can be suppressed. Note that the policy function, \(\varphi\), maps the current \((k, s)\) into \(\bar{k}\), next period’s \(k\). Hence, \(\varphi\) can be seen as an investment function, giving \(k_{t+1}\) as a function of wealth on hand, \(\bar{w}_t\) (itself a function of the capital stock, \(k_t\), and the current shocks, \(s_t\)).

A finite value function \(V\), that satisfies the Bellman equation (A-1) for all \((k, s)\) is a solution to the original maximization problem equation (4). \(V\) and \(\varphi\) satisfy

\(^{29}\) A third possibility is to introduce a fixed return (safe) asset, which would increase total accumulation (in the two assets taken together) while reducing accumulation of the risky asset because the return on the safe asset establishes a floor under the expected marginal return of the risky asset. This is similar to a deterministic model where the existence of the fixed return asset induces a switch from capital accumulation, subject to decreasing marginal productivity, to the fixed return asset.
the first-order condition:

\[(A-3) \quad u'(w(k, s) - \varphi(w(k, s))) = \beta E V'(w(\tilde{k}, \tilde{s})) \frac{\partial w(\tilde{k}, \tilde{s})}{\partial \tilde{k}} \]

and the envelope condition

\[(A-4) \quad V'(w) = u'(w - \varphi(w)). \]

Condition (A-3) equates the current marginal utility of consumption to the expected discounted value of a future extra unit of wealth on hand. Condition (A-4) states that the marginal value of wealth on hand, \(w\), equals the marginal utility of the corresponding consumption, \(w - \varphi(w)\).

It is typically not possible to solve the two conditions analytically. An approximation is used that restricts and rounds variables to a fine but finite grid of \((w, k, s)\) values. The key to the solution of the resulting discrete system is the observation that the program value, \(V(\cdot)\), and the policy function, \(w(\cdot)\), are functions of a single variable, \(w\). With only finite sets of values for \((k, s)\) and \(w\) rounded to the nearest grid value for wealth on hand, it is easy to calculate the probabilities \(p_{ij} = \text{Prob}[w(k_i, s) = w_j]\) so that the equation to solve becomes

\[(A-5) \quad V(w_\ell) = \max_i u(\ell - k_i) + \beta \sum_j p_{ij} V(w_j), \quad \text{for all } \ell. \]

This equation can be solved by iteration, with arbitrary initial values for \(V(w_\ell)\), \(\ell = 1, 2, \ldots\). Since \(\beta < 1\), the iteration converges.\(^{30}\) Given the solution, \(V(w_\ell)\), it is straightforward to derive the corresponding policy function, \(\varphi(w_\ell)\). The extension to the case with technical progress \((\tau > 0)\) is also straightforward.

This policy function is a proximate solution to the stochastic Ramsey problem. The approximation involves discretization and imposition of a finite end time. Obviously, this may affect the solution. The authors are currently experimenting with alternative solution methods that yield a policy function that is continuous in wealth on hand, unlike the method described here.

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