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Convergence, Shocks and Poverty

Chris Elbers[1]
Jan Willem Gunning[1,2]
Bill Kinsey[1]

[1] Faculty of Economics and Business Administration, Vrije Universiteit Amsterdam,
[2] Tinbergen Institute.

Convergence, Shocks and Poverty: Micro Evidence on Growth under Uncertainty

Chris Elbers, Jan Willem Gunning and Bill Kinsey
Free University Amsterdam

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Abstract

Using a unique panel data set for rural households in Zimbabwe we estimate a microeconomic model of growth under uncertainty, a stochastic version of the Ramsey model with livestock as the single asset. We use the estimation results in simulation experiments (over a 20-year period) to quantify the importance of convergence, household fixed effects and shocks. First, we find powerful convergence. In the absence of shocks and without household fixed effects there is rapid growth over the period (5.6% growth p.a. in per capita assets) even though there is no technical progress. The process of adjusting the capital stock (livestock) to its steady state value is - as expected - strongly equalising: the coefficient of variation (across households) of livestock ownership falls from 78% to 6%. Secondly, when we allow for household fixed effects - the case of conditional convergence - the aggregate growth rate is very similar but inequality remains high throughout the period. Finally, we find that shocks have strong and persistent effects. In this model shocks affect aggregate growth both *ex ante* and *ex post*. These effects are strong: shocks reduce aggregate growth over the period by a fifth and increase inequality substantially.

1 Introduction

Modern growth theory is based on an intertemporal optimisation model for an individual agent (e.g. Barro and Sala-i-Martin, 1995). In spite of this microeconomic basis empirical applications of growth theory have almost invariably used macro datasets. The alternative of testing micro theory on micro datasets has intuitive appeal but has so far been used rarely. There are two reasons for this. First, growth regressions require time series, but panel datasets for individual households have only recently become available. Secondly, where panel data sets do exist they are typically for advanced economies where capital markets are well developed so that volatility across times or states can be smoothed relatively easily. Micro data sets can then be used to test the Euler equation, under the assumption that the agent faces a given interest rate (e.g. Gourinchas and Parker, 2001). However, this assumption of a perfect capital market makes the agent's saving decisions independent of the production technology. This removes the curvature of the production function, the centerpiece of micro growth theory, from the analysis.

Developing countries are often characterised by very imperfect capital markets. In some studies this is captured by a borrowing constraint: the agent earns a fixed return on assets but assets must remain non-negative (e.g. Deaton, 1991). This still leaves the production technology off stage: the agent's non-asset income is exogenous and asset income does not reflect diminishing returns to investment. These assumptions are suitable for analysing the short-run effects of shocks but they are inappropriate for testing growth theory on micro data. We assume instead that there are *no* financial assets so that accumulation necessarily takes the form of investment in the capital stock used in the agent's own production process. While obviously extreme this assumption is quite realistic for rural households in Zimbabwe: they make very little use of financial assets and investment largely takes the form of building up the own livestock herd. The return to this asset is stochastic (households are exposed to shocks) and endogenous: the marginal productivity of livestock in the agricultural production process is decreasing in the capital stock.

In this paper we estimate a microeconomic model of growth under uncertainty - a stochastic version of the Ramsey-Cass-Koopmans model - using a unique panel dataset for rural households in Zimbabwe. The panel spans the period 1980-2000, a period in which these households' assets and incomes grew very rapidly, in spite of exposure to massive shocks. We derive the optimal accumulation equation for the households' key asset, livestock. The estimated micro growth model is used to address three questions.

The first question concerns convergence. In our model agents are heterogeneous: there are individual effects in productivity, agents differ in initial wealth and they are exposed to idiosyncratic (as well as to covariant) shocks. In the absence of shocks growth is an error correction response to the difference of the capital stock from its (household-specific) steady state value. This generates conditional convergence, as in deterministic macro growth models. Our first question is whether in our micro data set convergence is empirically important. We find that it is. In the absence of shocks the capital stock would have grown by 5.6% per capita over the 20-year period.

Our second question concerns the effect of shocks on growth. An increase in risk will (in most models[1]) affect the policy function, the optimal mapping from current to future wealth: each agent will adjust his investment behaviour in response to risk. As is well-known the sign of this *ex ante* effect is ambiguous.[2] (In our application it is negative: agents save less in response to an increase in risk.) There also is an *ex post* effect: actual shocks affect accumulation for a *given* policy function, i.e. controlling for the *ex ante* effect. We show that one component of the *ex post* effect is necessarily negative and that it persists: the mean of the ergodic distribution of the capital stock is reduced and this effect can be substantial. We use our estimated equation to assess whether the effect of risk on growth through these two channels is quantitatively important.

While there is much interest in the effect of risk on economic growth (e.g. Collier and Gunning, 1999) this issue is ignored in the growth regression literature, presumably because closed form solutions are difficult to find for models of growth under uncertainty. Typically, the estimation equation in growth regression is derived from a deterministic growth model with a stochastic component added only as an afterthought. Recently there has been a revival of interest in growth under uncertainty (e.g. Binder and Pesaran, 1999, de Hek, 1999; after early contributions such as Levhari and Srinivasan, 1969). However, these contributions treat special cases. For example, there is no *ex post* effect in the Levhari-Srinvasan model and no

[1] This is not necessarily true. For example, the canonical, loglinear growth regression can be derived from a growth model in which shocks affect growth *ex post* but not *ex ante* (see section *2).*

[2] In models with given returns to assets the sign of the effect is determined by the sign of the third derivative of the utility function: savings increase iff marginal utility is convex (concave) in consumption (e.g. Deaton, 1992, p. 29). When, however, the return on investment is endogenous (as in our model) this condition is neither necessary nor sufficient.

ex ante effect in the Binder-Pesaran model. Our model allows for both and hence for a more general investigation of the effects of risk on growth.

Our final question is about the relative strength of these two processes, convergence and shocks, on growth and hence on poverty. If convergence is relatively strong and households differ relatively little in productivity then growth will quickly eliminate much of the initial differences in wealth between agents and poverty will be rapidly eliminated. In this world asset redistribution can be a very effective initial policy. However, at some stage poverty becomes largely transient in the sense that most agents are not poor in the steady state. A negative shock can then push an agent back into poverty but he will grow relatively quickly out of poverty again. The transient nature of poverty calls for different policies, in particular for policies which improve access to financial instruments (insurance and credit) so that agents can better deal with negative shocks. Conversely, if convergence is relatively weak then initial differences can long persist. This, again, has important policy implications. Notably, initially policies must be carefully targeted, unlike in the first case. We assess the quantitative importance of the effects of growth and shocks on poverty by decomposing the change in poverty into the components due to growth and due to shocks. In the absence of shocks there would have been rapid growth; this would have substantially reduced poverty: the head count measure would have fallen from 87% to 47%. Under shocks poverty falls somewhat less: to 53%.

The structure of the paper is as follows. The next section sets out the model. Section 3 describes the survey data. Estimation and simulation results are presented in Section 4. Section 5 concludes.

2 The Model

We model growth as the outcome of individual intertemporal optimization decisions. There is a single good, used both for consumption and investment, production is subject to shocks and there is no credit or insurance. The agent's problem is:

$$\begin{aligned} V(k_0, z_0) &= \max_{\{c_t, k_{t+1}\}} E \sum_{t=0}^{\infty} \beta^t u(c_t) \qquad (1) \\ \text{subject to } \; k_{t+1} &= z_t g(k_t) - c_t \\ & \quad \text{given } k_0, z_0, \end{aligned}$$

where c denotes consumption, k the capital stock, u the instantaneous utility function, β a discount factor, z a shock, and $g(k) = f(k) + (1-\delta)k$ where

$f(k)$ is the production function and δ the depreciation rate. Time periods are identified by the subscript t. Shocks are serially independent and identically distributed. The agent maximizes expected discounted utility, taking the distribution of the shocks z_t as given. At the time the agent decides on c_t and k_{t+1} both k_t and the realization z_t are known. We assume that $u(c)$ is increasing, three times differentiable, strictly concave, that it satisfies the Uzawa conditions, and that $0 < \beta < 1$. The production function $f(k)$ satisfies $f(0) = 0$, is increasing, continuously differentiable and strictly concave.[3]

If a solution exists the model can be written in recursive form as the Bellman equation:

$$V(k, z) = \max_{\tilde{k}} u(zg(k) - \tilde{k}) + \beta \mathrm{E} V(\tilde{k}, \tilde{z}) \tag{2}$$

with associated policy function

$$\varphi(k, z) = \arg\max_{\tilde{k}} u(zg(k) - \tilde{k}) + \beta \mathrm{E} V(\tilde{k}, \tilde{z}),$$

where k and $\tilde{k}$ are the capital stocks at the beginning and the end of each period. In this form the model applies to every period so that time subscripts can be suppressed. The policy function φ maps the current (k, z) into $\tilde{k}$, next period's k. A value function V which satisfies the Bellman equation (2) for all (k, z) is a solution to the original maximization problem (1), see Stokey and Lucas (1989), section 9.1). V and φ satisfy the first order condition[4]

$$u'(zg(k) - \varphi(k, z)) = \beta \mathrm{E} V_k(\varphi(k, z), \tilde{z})$$

and the envelope condition

$$V_k(k, z) = u'(zg(k) - \varphi(k, z)) z g'(k).$$

The first condition equates the current marginal utility of consumption to the expected discounted value of a future extra unit of capital. The second condition states that the marginal value of capital can be obtained by allocating an extra unit of capital entirely to current consumption.

An interesting special case[5] arises if (a) capital depreciates fully ($\delta = 1$), (b) the production function is Cobb-Douglas, $g(k) = k^{\alpha}$, and (c) the

[3] We have not included a nonnegativity constraint for k_{t+1}, since our conditions ensure that non-negativity is satisfied.

[4] Partial derivatives will be denoted by subscripts, e.g. $V_k = \partial V / \partial k$.

[5] See e.g. Stokey and Lucas, 1989, section 2.2 or Obstfeld and Rogoff, 1996, section 7.4.

utility function has unitary relative risk aversion, $u(c) = \ln(c)$. Under these assumptions the policy function is

$$\tilde{k} = \varphi(k, z) = \alpha\beta z k^a. \tag{3}$$

Except for the full depreciation assumption this model is identical to the Solow growth model with production function $zg(k)$ and the savings rate equal to $\alpha\beta$. Substituting k_{t+1} for $\tilde{k}$ and k_t for k, and taking logs gives

$$\ln k_{t+1} = \ln(\alpha\beta) + \alpha \ln(k_t) + \varepsilon_t,$$

where $\varepsilon_t = \ln(z_t)$. Multiplying by α and defining income as $y = g(k)$, we obtain the canonical growth regression

$$\ln y_{t+1} - \ln y_t = \alpha \ln(\alpha\beta) + (\alpha - 1) \ln y_t + \varepsilon_t.$$

Elbers and Gunning (2002) show that this special case is in fact the *only* one consistent with the canonical growth regression. A striking implication of equation (3) is that the policy function is independent of the distribution of z. Hence an increase in risk (a mean preserving spread in the distribution of z) has (very implausibly) *no* effect on investment behaviour.

Returning to the general case, it is typically *not* possible to solve the two conditions analytically. In our empirical application we solve the Bellman equation on a finite grid of (k, z) values. This leads to the matrix equation

$$V_{ij} = \max_l u_{ijl} + \beta \sum_m p_m V_{lm},$$

where i refers to k, j to z, l to $\tilde{k}$, m to $\tilde{z}$ and (p_m) is the probability distribution of $\tilde{z}$ and $u_{ijl} = u(z_j g(k_i) - k_l)$. This equation can be solved by iteration, with arbitrary initial values for the elements of the matrix V. Since $\beta < 1$ the iteration converges. Given the solution V_{ij} it is straightforward to derive the policy function φ_{ij}. This function is strictly concave in k. The grid is, of course, a discrete approximation to the continuous variables k and z. For values in between grid points we use linear interpolation; for (k, z) values outside the grid we use the boundary values.

The model is illustrated in Figure 1. The curve labelled $\varphi[\sigma = 0, z = 1]$ depicts the deterministic case, when z_t is drawn from a degenerate distribution concentrated at $z = 1$. This is indicated by the standard deviation $\sigma = 0$ of the distribution. Starting at the initial capital stock k_0 the agent's capital stock will converge to the steady state value k^*. Such 'transitional' dynamics may imply substantial growth. For example, in our empirical application (where each agent starts with a capital stock far below the steady state) it amounts to almost 6% growth per annum over a twenty year period.

The curve labelled $\varphi[\sigma = \bar{\sigma}, z = 1]$ depicts the case of optimal growth under uncertainty where $z = 1$ is a drawing from a distribution with unit mean and positive variance $\bar{\sigma}^2$. We have drawn the curve for $z = 1$ to facilitate comparison with the deterministic case. In Figure 1 the effect of an increase in risk (higher σ) is to shift the policy function $\varphi(k, 1)$ upward: the *ex ante* effect of risk on saving is positive: $k^{**} > k^*$.[6]

Now consider the *ex post* effect of risk, *i.e.* the effect on capital accumulation of the actual shocks $z_1, z_2, ..$ for a given policy function $k_{t+1} = \varphi(k_t, z_t)$, reflecting the given distribution of z. The expected value of k_{t+1} (given k_t) is

$$E_z\varphi[\sigma = \bar{\sigma}] = \varphi^*(k) = \int \varphi(k, z)F(dz).$$

where F is the distribution of z. The fixed point of this mapping is given by $k^{***} = \varphi^*(k^{***})$. In the Figure we have drawn the curve $\mathrm{E}_z\varphi[\sigma = \bar{\sigma}]$ below $\varphi[\sigma = \bar{\sigma}, z = 1]$.[7]

The individual accumulation paths follow a Markov process. Define the ergodic distribution of k as $G(k) = \int\int_{\{\varphi(q,z)\leq k\}} G(dq)F(dz)$ with mean $\mathrm{E}k_\infty$. Note that

$$Ek_\infty = \int kG(dk) = \int_k\int_z \varphi(k, z)F(dz)G(dk) = \int_z\int_k \varphi(k, z)G(dk)F(dz)$$

$$< \int_z \varphi(Ek_\infty, z)F(dz) = \varphi^*(Ek_\infty)$$

where the strict inequality follows from the concavity of $\varphi(k, z)$ in k. It follows that at $k = Ek_\infty$ the curve $\mathrm{E}_z\varphi[\sigma = \bar{\sigma}] = \varphi^*$ lies above the 45° degree line. Hence $\mathrm{E}k_\infty < k^{***}$.

[6] This is the case in our empirical application but the result is, of course, not general. Levhari and Srinivasan (1969) show for the special case of a CRRA utility function and a linear production function $g(k) = k$ that the effect of risk on savings is positive (negative) if and only if the degree of relative risk aversion R exceeds (is less than) unity. Hence in that model risk has no effect on the policy function if the utility function is logarithmic ($R = 1$). The same is true for the special case of 3, defined by $u(c) = \ln c$ and $g(k) = k^\alpha$.

[7] This is the case if φ is strictly concave in z. However, our assumptions do not imply concavity or convexity of φ in z hence we cannot apply Jensen's inequality to establish the relative position of the two curves.

The figure illustrates that risk has two effects on growth. The precautionary motive changes saving in response to an increase in σ, as illustrated by the increase from k^* to k^{**}. By contrast, the effect of *ex post* shocks on growth is to move the expected long run value of the capital stock from k^{**} (via k^{***}) to $\mathrm{E}k_\infty$. In our Figure (and in our application) the net effect of the *ex ante* and *ex post* effects of shocks is negative: $\mathrm{E}k_\infty < k^*$. This result is not inevitable.[8] However, in the canonical case it is, since equation (3) implies that the three curves coincide so that $\mathrm{E}k_\infty < k^* = k^{**} = k^{***}$.

It is instructive to consider the magnitude of this negative effect in the canonical case. If z is distributed lognormally with $\ln z \sim N(-\sigma^2/2, \sigma^2)$ so that $\mathrm{E}z = 1$ then substituting y for $\ln k$, v for $\ln z + \sigma^2/2$ and A for $\ln \alpha\beta$ gives

$$y_{t+1} = \alpha y_t + v_t = v_t + \alpha v_{t+1} + \alpha^2 v_{t+2} + ..$$

where $v \sim N(0, \sigma^2)$. It follows that the ergodic distribution of y is normal: $y_\infty \sim N(0, \sigma^2/(1-\alpha^2))$. Hence

$$Ek_\infty = \exp\left(\frac{A}{1-\alpha}\right)\exp\left(\frac{-\alpha}{1-\alpha^2}\frac{\sigma^2}{2}\right) = k^* \exp\left(\frac{-\alpha}{1-\alpha^2}\frac{\sigma^2}{2}\right)$$

since $k^* = (\alpha\beta)^{1/(1-\alpha)}$. This may imply a substantial *ex post* effect of shocks on accumulation. For example, if $\alpha = .7$ and $\sigma = .5$ then $\mathrm{E}k_\infty = .84k^*$: the mean of the ergodic distribution of the capital stock falls 16% short of what it would be without shocks. If the initial position was e.g. $k_0 = .5k^*$ then the effect of shocks would be to eliminate about one third of the growth which would otherwise have occurred: $(k^* - \mathrm{E}k_\infty)/(k^* - k_0) = (1 - .84)/(1 - .5) = .32$. Hence even though in this special case risk has no *ex ante* effect, growth is very sensitive to changes in risk.

In our application we consider aggregate rather than individual investment. We allow for three types of heterogeneity: agents differ in their initial capital stock, in productivity and in shocks. In section 4 we use the estimated model in simulation experiments to derive the distributions of k_{h0}, k_h^*, k_h^{**}, and $\mathrm{E}k_{h\infty}$, where h denotes the agent. We then interpret the growth from $\bar{k}_0$ to $\bar{k}^*$ as *potential* growth (that is the growth which would occur in the absence of shocks). Similarly, the growth from $\bar{k}_0$ to $\bar{k}^{**}$ is potential growth corrected for the *ex ante* effect of shocks and the growth from $\bar{k}_0$ to $\mathrm{E}\bar{k}_\infty$ incorporates both the *ex ante* and the *ex post* effects of shocks.

[8] Recall that the *ex ante* effect (the change from k^* to k^{**}) can have either sign and that the *ex post* effect consists of the change from k^{**} to k^{***} (which, again, cannot be signed) and the change from k^{***} to $\mathrm{E}k_\infty$ (which is negative).

These results can be compared to actual growth from $\bar{k}_0$ to $\bar{k}_\infty$. In addition we consider changes in inequality by comparing the distributions around $\bar{k}^*, \bar{k}^{**}$, and $E\bar{k}_\infty$ to the original distribution around $\bar{k}_0$. Obviously, part of the inequality is caused by the agent fixed effects; see figure 2. This figure shows the risk-free policy function for two agents, who differ in productivity and therefore converge to a different steady state capital stock (conditional convergence). A second reason for long-run inequality is that the shocks to which agents are exposed are partly idiosyncratic.

3 Data[9]

In the early 1980s the government of Zimbabwe undertook a land reform programme which involved resettlement of peasant farmers and landless labourers on land formerly owned by commercial white farmers. To be eligible for resettlement household heads had to married (or widowed), not in formal employment, and not younger than 18 years 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 ha. of arable land.

In 1983/84 Bill Kinsey surveyed a sample of about 400 of the resettled households. The sampling frame consisted of all resettlement schemes established in the first two years of the programme. The sample was restricted to the three most important natural regions (NRs) or agro-climatic zones. In Zimbabwe these are designated as NR II ("moderately high agricultural potential"), III ("moderate potential") and 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) in 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 first interviewed in 1983/84, shortly after their resettlement and re-interviewed first in 1987 and then annually since 1992. They have now been followed for almost two decades, making this the only long-running panel dataset in Africa.[10] The questionnaire includes questions

[9] This section is based on Gunning *et al.* (2000) and Hoogeveen (2001).

[10] There is remarkably little sample attrition. Approximately 90% of households inter-

on crop production, sales, labour hiring, credit, food storage and antropometrics. Most importantly, it includes detailed information on the households' livestock ownership. The questionnaire contains data on various types of livestock (oxen, heifers, goats, etc.). These were aggregated by using constant market prices. The questions were partly retrospective; for example, the first survey round in 1983/84 asked about initial holdings in 1980. We have observations on k_{ht} for five points in time: 1980, 1992, 1993, 1996 and 2000. We have information on crop income for two points in time: 1993 and 1996.[11]

The empirical study of economic growth is riddled by measurement error problems (Bliss, 1999 and Carroll, 2001). We expect measurement errors to be less serious in our application. First, by using a micro data set we use a single method of measurement unlike growth regressions which have to rely on data collected by different institutions. Secondly, we can base our estimations on asset (livestock) rather than income data. While income and expenditure data are notoriously noisy the importance of livestock in most African societies suggests that livestock is measured fairly accurately.

4 Estimation and Simulation Results

In applying the stochastic Ramsey model to household data we make the following assumptions. First, household preferences are defined over per capita consumption. Secondly, the utility functions and discount rates are identical across households. Thirdly, the capital variable, k, is identified with livestock. Fourthly, households are heterogeneous in terms of productivity and the production function is linearly homogeneous in livestock and labour.[12] Indexing households by h the stochastic Ramsey model for an individual

viewed in 1983/84 were re-interviewed in 1997. There is no systematic pattern to the few households that drop out. Some were inadvertently dropped during the re-surveys, a few disintegrated (such as those where all adults died) and a small number were evicted by government officials. It should be noted that 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, pp. 45-46).

[11] We are grateful to Trudy Owens who provided us with the aggregate crop income data which she constructed.

[12] This allows us to write the production function in the intensive form $g(k)$ as in section 2.

household can be written as:

$$\max_{c_{ht},k_{ht}} \sum_{t=0}^{\infty} E_t \beta^t u(c_{ht})$$

subject to

$$\begin{aligned} k_{h,t+1} &= b_t z_{ht} g_h(k_{ht}) - c_{ht} \\ & \text{given } k_{h0}, z_{h0}, b_0, \end{aligned}$$

where c denotes *per capita* consumption, k is livestock per capita, and $bzg(k)$ is the livestock availability per capita. Here b_t is a covariant shock, and z_{ht} an idiosyncratic shock.

The function $g_h(k)$ is given by

$$g_h(k_{ht}) = (1-\delta)k_{ht} + \lambda a_h f(k_{ht}),$$

where a_h is a household effect, estimated as a function of household characteristics. $f(k)$ is a production function in intensive form and δ is the depreciation rate $(0 < \delta < 1)$.[13] The parameter λ is a conversion parameter to account for the difference in dimensions between capital, k, and output, $f(k)$.

We assume that the utility function is of the CRRA-type, $u(c) = c^{\gamma}$, with parameter $\gamma < 1$ (risk aversion) and that the production function is CES with parameters ρ and ψ: $f(k) = (1+\psi(k^{-\rho}-1))^{-1/\rho}$. We assume the z_{ht} are independent across h and t and identically and lognormally distributed, with parameters $(0, \sigma_{\log(z)})$. The variance $\sigma^2_{\log(z)}$ is to be estimated. Covariant shocks are identified with rainfall volatility: $b_t =$rainfall$^{\pi}$, where π is a parameter to be estimated. Rainfall is approximately lognormally distributed and we impose this distribution. Households have rational expectations and therefore know the distribution of $b_t z_{ht}$.

Demographic change (birth, death and disability) in the context of Zimbabwean farmers is largely unplanned; we therefore incorporate it in the shock z_{ht}.

We first estimate the function $a_h f(k_h)$ by maximum likelihood. The usual objection to direct estimation of the productioin function: that outputs and inputs are determined simultaneously does not carry much force

[13] An important implication of this formulation is that $g'(k) \geq (1-\delta)$ for all k. This implies that the policy function φ is much steeper than suggested in Figure 1 (or in the canonical case with full depreciation: $\delta = 1$). Vertical shifts in the policy function therefore have strong effects on long-run variables such as k^*.

	Estimate	t-score
NR II	5.4611	7.73
NR III	4.6838	6.63
NR IV	4.5286	6.40
1996	-0.1226	-3.45
household size	-0.0285	-2.66
education	0.0372	2.47
ψ	0.5096	7.18
ρ	-0.4907	-2.81

Table 1: Production function estimates

in the present situation. Since households are exposed to shocks the optimal use of inputs is continually disturbed.[14] The dependent variable, crop income, is available for two years, 1993 and 1996. We specify a_h as a linear function of household size and the education of the household head with a household random effect and dummies for three natural regions and the year 1996. The results are shown in Table 1.[15]

Note that - as expected - productivity is highest in NR II and lowest in NR IV, that the effect of household size is negative and that productivity is increasing in education. The estimated value for ρ implies a substitution elasticity of about 2.

This leaves six parameters to estimate: γ, the parameter of the utility function; β, the discount factor; λ, the conversion parameter; δ, the rate of depreciation; π, the rainfall elasticity; and $\sigma_{\log(z)}$, the standard deviation of the idiosyncratic shocks. We estimate these parameters by Simulated Pseudo Maximum-Likelihood.[16] For a given choice of parameter values, a vector θ, we solve, for each household h, the Bellman equation, deriving the policy function φ_h. Using the policy function and the initial capital stocks k_{h0}, we then generate 10,000 paths of k_{ht}, using observed rainfall data and drawing independent shocks from the distribution of z_{ht}. For each household we calculate the mean values and the covariance matrix of $k_{ht'}$ over the 10,000 paths, where t' refers to the five years for which we have

[14] Elbers and Gunning (2002) argue that the model is identified from income dynamics alone. This would suggest that it is unnecessary to estimate the production function separately. However, our two-step procedure is more practical since it reduces the dimensionality of the estimation problem.

[15] The results are virtually the same if no random effect is included: in that case the estimates for θ and ρ are 0.5340 and -.4713 respectively.

[16] See e.g. Gouriéroux and Montfort (1996), section 3.2.

Parameter	Estimate	Standard error
γ	0.0077	.001
β	0.7949	.000
λ	0.9231	.000
δ	0.1512	.013
π	0.3136	.050
$\sigma^2_{\log(z)}$	0.0818	.040

Table 2: Second-step estimation results

		Mean	Inequality (σ)	Head count	Growth rate
Initial situation	k_0	0.77	0.60	0.87	
Unconditional convergence		2.29	0.13	0.00	5.6%
Conditional convergence	k^*	2.40	1.98	0.47	5.8%
Ex ante effect of shocks	k^{**}	2.25	1.54	0.41	5.5%
Ex post effect of shocks	Ek_∞	2.09	2.21	0.53	5.1%

Table 3: Simulation results

observations on k. We then calculate the likelihood of the sample. This gives us the likelihood $\mathcal{L}(\theta)$ and we use a hill-climbing technique to maximize it. The maximum likelihood estimates are shown in Table 2.

The estimated value of γ is very close to zero, implying log utility and a unitary degree of relative risk aversion. The estimate of β suggests a high degree of impatience: a discount rate of 26%. The depreciation rate δ should be interpreted as a net rate, reflecting not just the aging and death of animals but also livestock births. Note that our estimates support only one of the three assumptions underpinning the canonical growth regression: log utility; our estimates for ρ and δ are very different from the Cobb-Douglas and full depreciation assumptions. The last column in table 2 shows standards errors derived from (very preliminary) bootstrapping experiments.

We now use the estimated parameters to simulate accumulation paths k_{ht}. We run the simulations over a 20-year period, 1980-2000, starting from the given observed value of k_{h0}. For each household we calculate the mean over 10,000 paths of the final value of the capital stock, Ek_{h20}. We then characterise the distribution across households of these means by its mean and standard deviation (σ), as a measure of inequality. The simulation results are summarized in Table 3.

The first row describes the initial situation, in 1980. While the size of the holding was identical for all resettled households there was substantial initial inequality in livestock ownership. (Many households started with none: $k_0 = 0$.) The second row presents the riskless counterfactual in the absence of household productivity differences, *i.e.*, $a_h = \bar{a}$. Here households experience no shocks during the simulation ($z_{ht} = 1$ for all h and t) and perceive no shocks *ex ante* (*i.e.* we impose $\sigma_{\log(z)+\log(b)} = 0$). This simulation shows very substantial asset accumulation: the mean value of k_h grows from 0.77 to 2.29, an annual growth rate of 5.6%. Note that since there is no technical change the only source of this growth is that households start very far from the steady state. Since in this case the steady state is the same for all households inequality is substantially reduced during the accumulation process. In the next row we allow for productivity differences so convergence is conditional. This happens to increase the growth rate but most importantly inequality remains substantial in the long run: the coefficient of variation in the intial situation and after 20 years are very similar.

The fourth row introduces the effect of risk, but (artificially) only in the *ex ante* sense. Households now calculate their policy rules $\varphi(z, k)$ on the basis of the estimated value of $\sigma_{\log(z)+\log(b)}$. However, while they are now exposed to the actual rain shocks, they experience no actual idiosyncratic shocks: $z_{ht} = 1$ for all h and t. The introduction of shocks has a negative effect on capital accumulation but reduces inequality substantially. The final row does include the *ex post* effect of idiosyncratic shocks: household means are now calculated across 10,000 paths, defined by drawings of z_{ht} from the lognormal distribution.[17] This further reduces livestock accumulation while inequality increases.

It may be noted that of the capital accumulation which would have occurred in the absence of risk (from a mean value of 0.77 to 2.40) about a fifth is eroded by shocks. In this particular case about half of this loss is the *ex ante* effect of shocks and about half is the *ex post* effect.

5 Conclusion

We believe the paper makes three contributions. First, we have proposed a framework for analysing the long-run effects of shocks, clarifying the distinction between the *ex ante* and *ex post* effects of shocks on growth. In the

[17] Note that in terms of Figure 1 we present estimates of k^*, k^{**}, Ek_∞ but not of k^{***}. This is because k^{***} is a one-period ahead concept (the expected value of k_{t+1} given the value of k_t) whereas the other three concepts can be interpreted as the expected long-run value of k: Ek_∞ (in our simulations approximated by Ek_{20}), given the starting value k_0.

empirical literature the effects of shocks on growth are often assumed away by modelling income as a stochastic but exogenous process. Conversely, much of the theoretical literature makes special assumptions which rule out either the *ex ante* or the *ex post* effect. We have shown that both can be quantitatively important. This suggests a redirection of future research on economic growth and on poverty dynamics with an explicit modelling of the role of risk. Secondly, we have shown that it is possible to estimate micro models of growth under uncertainty: there is no need to stay within the strait jacket of the highly restrictive empirical specifications which have become standard in the growth regressions literature. Finally, our application showed that for a sample of resettled Zimbabwean households (observed for almost a generation) shocks have had very substantial *long run* effects, both on capital accumulation and on poverty. (This could not have been established with the usual, descriptive methodology for decomposing poverty into structural and transitory components.) We believe this is the first micro-based estimate of the empirical importance of shocks in the process of growth. Its magnitude in Zimbabwe suggests that policy makers need to pay much more attention to reducing shocks and to helping households in risk management.

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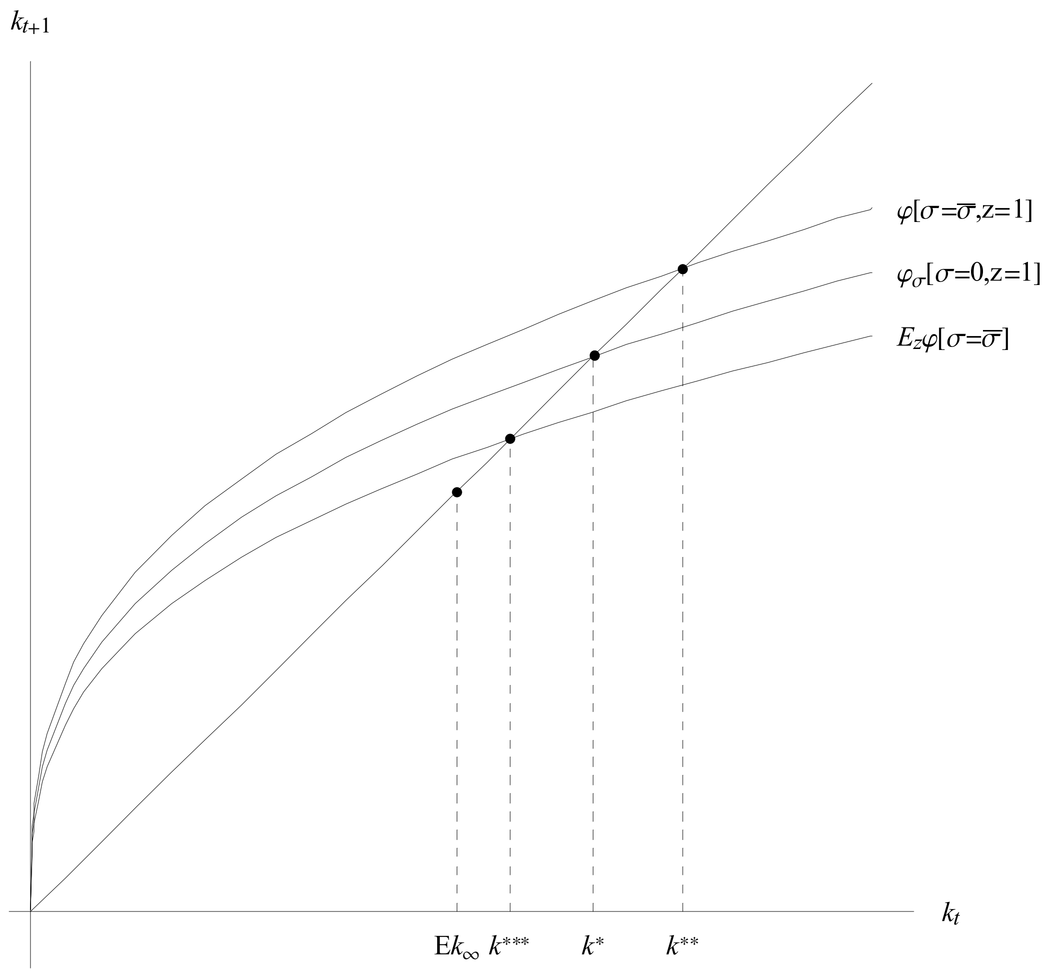

Figure 1: Individual accumulation functions

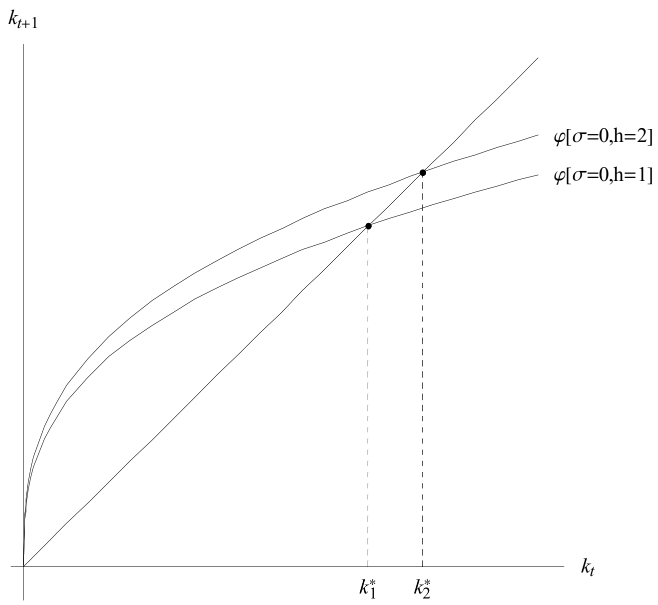

Figure 2: Conditional convergence