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GROWTH AND EPIDEMIC DISEASES

Clive Bell and Hans Gersbach

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Clive Bell, Universität Heidelberg
Hans Gersbach, Universität Heidelberg and CEPR

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Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

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ABSTRACT

Growth and Epidemic Diseases*

We study the formation of human capital and its transmission across generations when a society is assailed by an epidemic disease such as AIDS. We establish that the disease can severely retard economic growth, even to the point of leading to an economic collapse. We also show that the epidemic may exacerbate inequality. Pooling health risks in the society puts the society on a 'make and break' road.

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Clive Bell
Süd-Asien Institut
Universität Heidelberg
Grabengasse 14
69117 Heidelberg
GERMANY
Email: clive.bell@urz.uni-heidelberg.de

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Hans Gersbach
Alfred-Weber-Institut
Universität Heidelberg
Grabengasse 14
69117 Heidelberg
GERMANY
Tel: (49 6221) 543 173
Fax: (49 6221) 543 578
Email: gersbach@uni-hd.de

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1 Introduction

While the costs of epidemic diseases in terms of human suffering and lives lost are undeniably large, estimates of the associated macroeconomic costs have tended to be more modest. For example, studies that focus on AIDS in Africa – the continent where the epidemic has hit the hardest – calculate the annual loss of GDP to be around one percent (see Arndt and Lewis (2000), Bonnel (2000), Kambou et al. (1992), Over (1992), Sackey and Raparla (2000, 2001a,b). These estimates all stem from a particular view of how the economy functions, namely, where the AIDS-induced increase in mortality reduces the pressure of population on existing land and capital, thereby raising the productivity of labor. Even if there is a decline in savings and investment (from the reallocation of expenditures towards medical care), its impact on GDP growth is dampened by the countervailing effect of increased labor productivity. Consequently, the net effect on the growth rate of per-capita GDP is very modest.[1]

In this paper, we take a different view of how the economy functions over the long run; one which emphasizes the importance of human capital and transmission mechanisms across generations. The formation of human capital, which should be thought of as the entire stock of knowledge and abilities (general and specific) embodied in the population, is likely to play a leading role in promoting economic growth. We establish that AIDS can severely retard economic growth, even to the point of leading to an economic collapse. The argument is made in three steps.

First, AIDS destroys existing human capital in a selective way. It is primarily a disease of young adults and reduces their productivity by making them sick and weak. It then kills them in their prime, thereby destroying the human capital progressively built up in earlier years.

Second, AIDS weakens or even ruins the mechanisms that generate human capital formation.

[1] Young (2004) calculates the impact of the AIDS epidemic on future living standards in South Africa. He finds that the labor supply effect dominates such that from the perspective of per capita living standards, the epidemic is a boon to the generations which survive and succeed it.

In the household, the quality of child-rearing depends heavily on the parents' human capital, as broadly defined above. If one or, worse, both parents die while their offspring are still children, the transmission of knowledge and potential productive capacity across the two generations will be weakened. At the same time, the loss of income due to disability and early death reduces the lifetime resources available to the family, which may well result in the children spending much less time (if any at all) at school. Finally, the chance that the children themselves will contract the disease in adulthood makes investment in their education less attractive, even when both parents themselves remain uninfected. The weakening of these transmission processes is insidious; its effects are felt only over the long run, as the poor education of children today translates into low productivity of adults a generation later.

Third, as the children of AIDS victims become adults with little education and limited knowledge received from their parents, they are in turn less able to raise their own children and to invest in their education. A vicious cycle ensues. If nothing is done, the outbreak of the disease will eventually precipitate a collapse of economic productivity. In the early phases of the epidemic, the damage may appear to be slight. But as the transmission of capacities and potential from one generation to the next is progressively weakened and the failure to accumulate human capital becomes more pronounced, the economy will begin to slow down with the growing threat of a collapse to follow.

This is the essence of the argument which we will develop in a simple model. For that purpose, we combine the overlapping generations (OLG) model of Bell and Gersbach (2002), which analyzes the nexus of child labor, education and growth, with disease-ridden environments. Parents have preferences over current consumption and the level of human capital attained by their children, making due allowances for early mortality in adulthood. The decision about how much to invest in education is influenced by premature adult mortality in two ways: first, the family's lifetime income depends on the adults' health status, and second, the expected pay-off depends on the level of premature mortality among children when they attain adulthood. The outbreak of AIDS leads to an increase in such mortality, and if the prevalence of the disease becomes sufficiently high, there may be a progressive collapse of human capital and productivity.

We also show that AIDS initially exacerbates inequality. If the children left orphaned are not given the care and education enjoyed by those whose parents remain uninfected, the weakening of the inter-generational transmission mechanism will express itself in increasing inequality among the next generation of adults and the families they form. Finally, we examine whether pooling as an alternative form of social organization where members of the extended family take in orphans might protect a society from a collapse. We show that pooling puts the society on a "make or break" road in the following sense. Pooling can lead to a collapse, which might otherwise be avoidable, especially if the disease causes quite severe mortality. In a less lethal disease environment, in contrast, pooling is a form of social organization that helps fend off the collapse that would occur under a nuclear family structure.

The purpose of this paper is to develop a framework that focuses on the transmission of human capital between generations when a society is assailed by an epidemic disease. The present framework can be calibrated and applied to public policy. In a companion paper, Bell, Devarajan and Gersbach (2004), the model is calibrated to South Africa and yields the following results. First, with the mortality profile prevailing before the outbreak of the epidemic, the economy was already launched on a path of modest, but sustained growth. Second, in the counterfactual absence of the outbreak, full and universal education would be achieved by 2020. Third, if the epidemic continues unabated at maturity, an economic collapse will set in, reaching a low-level equilibrium in three generations. Fourth, programs to combat the disease and support needy families can avert such a collapse, but they all imply a heavy burden and their efficiency depends on family structure and whether school-attendance subsidies are feasible. As illustrated in Bell, Devarajan and Gersbach (2004) the present framework may serve as a model for determining the fiscal efforts necessary to successfully combat an epidemic disease and its economic effects.

In addition to the contributions to the macroeconomic effects of AIDS discussed above, the present paper is related to other strands of the literature. It is motivated, in part, by the empirical observation that good health has a positive and statistically significant effect on aggregate output (Barro and Sala-I-Martin, 1995; Bloom and Canning, 2000; Bloom, Canning and Sevilla, 2001). The recent report by the Commission on Macroeconomics and Health (WHO, 2001) has also stressed that widespread diseases are a formidable barrier to economic growth.

Our paper is an example of a recent literature in economic growth that endogenously generates the transition through different regimes. The literature has been initiated by Galor and Weil 1999, 2000 who describe within a single unified framework long-run development processes from an epoch of Malthusian stagnation to a state of sustained economic growth in modern times. We focus on how negative health shocks may induce a transition from a state of continuous growth to a state of backwardness and poverty. Our paper is complementary to Lagerlöf (2003) who also examines the long-run development process in Western Europe. He considers in addition epidemic shocks that affect the death rate of children. He shows that a series of mild epidemic shocks causes a transition from a Malthusian stage to the Industrial Revolution since population expands which raises productivity in human capital production and thus income growth. In our paper, a negative epidemic shock affects parents in their young age causing an interruption of the transmission of human capital across generations which may initiate a progressive decline of the economy. Hence, Lagerlöf (2003) and our paper develop different human capital stories on how epidemic diseases might affect growth.

The plan of the paper is as follows. The basic model is set out in section 2. The dynamics of the system under an exogenous mortality profile, corresponding to some given disease environment, are analyzed in section 3. In section 4, we identify conditions for an economic collapse. We illustrate plausible time paths by an example in section 5. In section 6, we examine pooling as an alternative form of organization that has both advantages and drawbacks in such a setting concerning the likelihood of a collapse. The last section is devoted to an assessment and applications of the overall results and the most fruitful directions of future research.

2 The Model

2.1 The macroeconomic environment

We extend the OLG-model of Bell and Gersbach (2002) by introducing premature mortality among adults in the context of an epidemic disease such as AIDS. There are two periods of life, childhood and adulthood, whereby the course of adulthood runs as follows. On becoming adults, individuals immediately form families and have their children. When the children are very young, they can neither work nor attend school. Since the only form of investment is education, the family's full income is wholly consumed in this phase. Only after this phase is over do the adults learn whether they will die prematurely, and so leave their children as half- or full orphans. Early in each generation of adults, therefore, all nuclear families are sorted into one of the following four categories:

1. both parents survive into old age,
2. the father dies prematurely,
3. the mother dies prematurely,
4. both parents die prematurely.

These states are denoted by $s_t \in S_t := \{1,2,3,4\}$. The probability that a family formed at the start of period t lands in category s_t is denoted by $\pi_t(s_t)$. The population is assumed to be large enough that this is also the fraction of all families in that state after all premature adult deaths have occurred. An important consequence of such mortality is that it results in heterogeneity among each cohort of families. Once their states have been revealed, families make their decisions accordingly, as will be described below.

We turn to the formation of human capital. Consider a family at the start of period t. Let λ_t^f and λ_t^m denote, respectively, the father's and mother's endowments of human capital, and let $\Lambda_t(s_t)$ denote their total human capital when the family is revealed to be in state s_t. Then,

$$\Lambda_t(1) = \lambda_t^f + \lambda_t^m,\ \Lambda_t(2) = \lambda_t^m,\ \Lambda_t(3) = \lambda_t^f,\ \Lambda_t(4) = 0. \tag{1}$$

An additional source of heterogeneity is ruled out in advance:

Assumption 1. There is assortative mating: $\lambda_t^f = \lambda_t^m \ \forall t$.[2]

Hence, (1) specializes to $\Lambda_t(1) = 2\lambda_t, \Lambda_t(2) = \Lambda_t(3) = \lambda_t, \Lambda_t(4) = 0$, where the superscripts f and m may be dropped without introducing ambiguity.

Human capital is assumed to be formed by a process of child-rearing combined with formal education in the following way. In the course of rearing their children, parents give them a certain capacity to build human capital for adulthood, a capacity which is itself increasing in the parents' own human capital. This gift will be of little use, however, unless it is complemented by at least some formal education, in the course of which the basic skills of reading, writing and calculating can be learned. Let the proportion of childhood devoted to education be denoted by $e_t \in [0,1]$, the residual being allocated to work, and for simplicity, let all the children in a family be treated in the same way.[3]. Expressed formally, the human capital attained by each of the children on reaching adulthood is assumed to be given by

$$\lambda_{t+1} = \begin{cases} z(s_t) f(e_t)\Lambda_t(s_t) + 1, & s_t = 1,2,3 \\ \xi & s_t = 4 \end{cases} \tag{2}$$

[2] This assumption is made solely for simplicity of the exposition of our main arguments.

[3] A seminal economic analysis of child labor has been developed in Basu and Van (1999). For a recent survey see Basu (1999)

Beginning with the upper branch of (2), the term $z_t(s_t)$ represents the strength with which capacity is transmitted across generations. It is plausible that the father's and mother's contributions to this process are not perfect substitutes, in which case, $2z(1) > \max[z(2), z(3)]$ and $z(2)$ may not be equal to $z(3)$. For simplicity, however, we introduce

Assumption 2. $z(2) = z(3) \geq z(1) \geq z(2)/2 = z(3)/2$.

$z(1) = z(2) = z(3)$ which holds when the parents are perfect complements and $2z(1) = z(2) = z(3)$ when they are perfect substitutes. Assumptions 1 and 2 allow the upper branch of (2) to be rewritten as

$$\lambda_{t+1} = (3 - s_t)z(s_t)f(e_t)\lambda_t + 1, \quad s_t = 1, 2 \tag{3}$$

both types of single-parent families being identical in this respect. The function $f(\cdot)$ may be thought of as representing the educational technology – translating time spent on education into learning.

Assumption 3. $f(\cdot)$ is a continuous, strictly increasing and differentiable function on [0, 1], with $f(0) = 0$.

Observe that assumption 3 implies that children who do not attend school at all attain, as adults, only some basic level of human capital, which has been normalized to unity. A whole society of such adults will be said to be in a state of backwardness.

According to the lower branch of (3), there is a miserable outcome for full orphans who do not enjoy the good fortune of being adopted or placed in (good) institutional care. Deprived of love and care, and being left to their own devices, they go through childhood uneducated, to attain human capital ξ (≤ 1) in adulthood.

The next step is to relate human capital to current output, which takes the form of an aggregate consumption good. The following assumption implies that current output will accrue to families as income in proportion to the amounts of labor, measured in efficiency units, that they supply.

Assumption 4. Output is proportional to inputs of labor measured in efficiency units.

A natural normalization is that an adult who possesses human capital in the amount λ_t is endowed with λ_t efficiency units of labor, which he or she supplies completely inelastically. A child's contribution to the household's income is given as follows: In view of the complementarity between the potential capacity received during rearing and formal education, a child will supply at most one efficiency unit of labor during childhood. Indeed, it is plausible that a child's efficiency will be somewhat lower than the parents', *ceteris paribus*, on grounds of age alone. To reflect these considerations, let a child supply $\gamma(1-e_t(s_t))$ efficiency units of labor when the child works $1-e_t(s_t)$ units of time. It is plausible to assume that $\gamma \in (0,\xi)$, i.e. a full-time working child is at most as productive as an adult who happened to be an orphan. A family with n_t children therefore has a total income in state s_t $(s_t = 1,2,3)$ of

$$y_t(s_t) = \alpha[\Lambda_t(s_t) + n_t\big(1-e_t(s_t)\big)\gamma] \tag{4}$$

where the scalar $\alpha(>0)$ denotes the productivity of human capital, measured in units of output per efficiency unit of labor input.

2.2 The Household's Behavior

It is assumed that all allocative decisions lie in the parents' hands, as long as they are alive. We rule out any bequests at death, so that the whole of current income, as given by (4), is consumed. Concerning the allocation of consumption within the family, let the husband and wife enjoy equality as partners, and let each child obtain a fraction $\beta \in (0,1)$ of an adult's consumption if at least one adult survives. Full orphans $(s_t = 4)$ do not attend school, and consume what they produce as child laborers.

From (2), the budget sets of single-mother and single-father households with the same endowments of human capital and the same number of children are identical. In the absence of any taxes or subsidies, the household's budget line may therefore be written as

$$[(3-s_t)+n_t\beta]c_t(s_t)+\alpha n_t\gamma e_t(s_t)=\alpha[(3-s_t)\lambda_t+n_t\gamma], \quad s_t=1,2 \tag{5}$$

where $c_t(s_t)$ is the level of each adult's consumption. The expression on the LHS represents the costs of consumption and the opportunity costs of the children's schooling. The expression on the RHS is the family's so-called full income[4] in state $s_t=1,2,3$, whereby assumption 1 ensures that states 2 and 3 are identical where the budget set is concerned. Observe that single-parent households not only have lower levels of full income than their otherwise identical two-parent counterparts, but that they also face a higher relative price of education, defined as $\alpha n_t\gamma/[(3-s_t)+n_t\beta]$.

In keeping with the rather imperfect state of knowledge about the relationship between AIDS and fertility, we make no attempt to model fertility in a sophisticated way. Let all mortality among children occur in infancy, and suppose that so-called 'replacement fertility' behavior is unhindered by premature adult mortality. Then:

Assumption 5. Couples have children while they are young until some exogenously fixed number have survived infancy, a target that may vary from period to period.

With n_t thus fixed, the adults wait until the state of the family becomes known, and the survivor(s) then choose some feasible pair $(c_t(s_t),e_t(s_t))\geq 0$ subject to (6).

Parents are assumed to have preferences over their own current consumption and the human capital attained by their children in adulthood, taking into account the fact that an investment in a child's education will be wholly wasted if that child dies prematurely in adulthood. Let mothers and fathers have identical preferences, and for two-parent households, let there be no 'joint' aspect to the consumption of the pair $(c_t(1),e_t(1))$: each surviving adult derives (expected) utility from the pair so chosen, and these utilities are then added up within the family. In effect, whereas $c_t(1)$ is a private good, the human capital of the children in adult-

[4]A household's full income is the scalar product of its endowment vector and the vector of market prices. Here, output is taken as the numéraire.

hood is a public good within the marriage. Since all the children attain λ_{t+1}, the only form of uncertainty is that surrounding the number who will not die prematurely as adults, which is denoted by a_{t+1}. Let preferences be separable, with representation

$$EU_t(s_t) = (3 - s_t)[u(c_t(s_t)) + E_t a_{t+1} \nu(\lambda_{t+1})], \quad s_t = 1,2 \tag{6}$$

where the contribution $\nu(\lambda_{t+1})$ counts only when death does not come early, E_t is the expectation operator and $E_t a_{t+1}$ is the expected number of children surviving into old age. The sub-utility functions $u(\cdot)$ and $v(\cdot)$ are assumed to be increasing, continuous, concave and twice-differentiable. Denoting by $\pi_{t+1}(s_{t+1})$ the parents' subjective probability that a child will find itself in state s_{t+1} in period $t+1$, so that $\sum_{s_{t+1}=1}^{4} \pi_{t+1}(s_{t+1}) = 1$, and recalling assumption 1 and that all children are treated identically, we obtain

$$E_t a_{t+1} \nu(\lambda_{t+1}) = n_t \kappa_{t+1} \nu(\lambda_{t+1}),$$

where

$$\kappa_{t+1} \equiv [1 + \pi_{t+1}(1) - \pi_{t+1}(4)]/2 \tag{7}$$

and λ_{t+1} is given by the upper branch of (3). Observe that $\kappa_{t+1} = 1$ if and only if there is no premature adult mortality ($\pi_{t+1}(1) = 1$), and that $\kappa_{t+1} < 1$ otherwise. A reduction in κ_{t+1}, therefore, effectively entails a weaker taste for the children's education. By way of illustration, let premature mortality among adults be independently and identically distributed, and denote the probability that an adult will survive to old age by p_t. Then,

$$\pi_t(1) = p_t^2,\ \pi_t(2) = \pi_t(3) = p_t(1 - p_t),\ \pi_t(4) = (1 - p_t)^2,\ \kappa_t = p_t$$

It will be convenient in what follows to rewrite (6) as

$$EU_t(s_t) = (3 - s_t)[u(c_t(s_t)) + n_t \kappa_{t+1} \nu(z(s_t) f(e_t) \Lambda_t(s_t) + 1)], \quad s_t = 1,2 \tag{8}$$

A family in state $s_t (= 1,2,3)$ in period t solves the following problem:

$$\max_{[c_t(s_t), e_t(s_t)]} EU_t(s_t) \text{ s.t.}(6),\ c_t(s_t) \geq 0,\ e_t(s_t) \in [0,1]. \tag{9}$$

Let $[c_t^0(s_t), e_t^0(s_t)]$ solve problem (9), whose parameters are $(\kappa_{t+1}, \lambda_t, n_t, s_t, \alpha, \beta, \gamma)$. By the envelope theorem, we have

$$\frac{\partial EU_t(s_t)}{\partial \lambda_t} > 0, \frac{\partial EU_t(s_t)}{\partial \kappa_{t+1}} > 0.$$

Since current consumption is maximized by choosing $e_t = 0$, it follows that the parents' altruism towards their children must be sufficiently strong if they are to chose $e_t > 0$.

Assumption 6. Both goods are non-inferior.[5]

It follows at once that:

$$\frac{\partial e_t^0(s_t)}{\partial \Lambda_t(s_t)} \geq 0 \text{ and } \frac{\partial c_t^0(s_t)}{\partial \Lambda_t(s_t)} \geq 0$$

Inspection of $EU_t(s_t)$ reveals that an increase in κ_{t+1} induces an increase in $e_t^0(s_t)$ if $0 < e_t^0(s_t) < 1$ and preserves $e_t^0(s_t) = 1$; for it increases the weight on $\nu(\lambda_{t+1})$ relative to that on $u(c_t(s_t))$. An increase in κ_{t+1} therefore has the opposite effect on $c_t^0(s_t)$.

The remaining comparative static results concern the effect of family status in the present on investment in, and the accumulation of, human capital. Note that the upper boundaries of the budget sets in the cases $s_t = 2$ and $s_t = 3$ lie strictly inside that associated with $s_t = 1$ and that the price of c_t relative to e_t is lower for $s_t = 2, 3$ than for $s_t = 1$. We then obtain:

Lemma 1

Suppose λ_t is given. Then, under assumptions 1, 2 and 6,

(i) $\quad e_t^0(1) \geq e_t^0(2) = e_t^0(3)$

(ii) $\quad \lambda_{t+1}(1) \geq \lambda_{t+1}(2) = \lambda_{t+1}(3)$

(iii) $\quad \partial e_t^0(s_t)/\partial \kappa_{t+1} > 0$ *if* $0 < e_t^0(s_t) < 1$.

We introduce the assumption that altruism is not operative when the adults are uneducated:

Assumption 7. For $\Lambda_t(1) \leq 2$, $e_t^0(1) = 0$.

[5]Note that Λ_t enters both the budget constraint and the utility that adults derive from λ_{t+1}. Therefore, the definition of inferior goods is not the same in this particular set-up as the textbook description.

Part (i) of Lemma 1 then yields $e_t^0(2) = e_t^0(3) = 0$ as a trivial corollary.

2.3 Dynamics

Recalling that $e_t^0(s_t)$ is chosen so as to solve problem (9), equation (2) may be written

$$\lambda_{t+1} = \begin{cases} z(s_t)\, f\left(e_t^0(\Lambda_t(s_t), s_t, \kappa_{t+1})\right)\Lambda_t(s_t) + 1, & s_t \;= 1,2,3 \\ \xi, & s_t \;= 4 \end{cases} \tag{10}$$

Equation (10) describes a random dynamical system, in the sense that although each child attains λ_{t+1} in adulthood with certainty, he or she can wind up in any of the states $s_{t+1} \in \{1,2,3,4\}$ after reaching adulthood and forming a family. In the absence of premature mortality the above system has at least two steady states if $z(1)f(1)2\lambda^a + 1 \geq \lambda^a$, where λ^a is the lowest level of an adult's human capital such that a two-parent household chooses full education for the children in such an environment.

The typical dynamics in the absence of premature mortality are illustrated in figure 1, where Λ^d (> 2) denotes the smallest endowment of the adults' human capital such that they just begin to send their children to school. $\Lambda^a\,(= 2\lambda^a)$ denotes the corresponding endowment at which children finally enjoy full-time schooling. As depicted, the system has two steady states. First, there is the state of backwardness ($\Lambda = 2$). This stable steady state is a poverty trap, wherein all generations are at the lowest level of human capital. Second, there is an unstable steady state ($\Lambda_t = \Lambda^* \;\forall\; t$), in which the parents' human capital is such that they choose a positive level of education for their children that also yields each of the latter $\Lambda^*/2$ in adulthood. To be precise, Λ^* satisfies

$$\frac{\Lambda^*(1)}{2} = z(1)\, f\left(e_t^0(\Lambda^*(1), 1, 1)\right)\Lambda^*(1) + 1,$$

where $\pi_t(1) = 1$ for all t. Observe that starting from any $\Lambda > \Lambda^*$, unbounded growth is possible if and only if $2z(1)f(1) \geq 1$, and that the growth rate approaches $2z(1)f(1) - 1$ asymptotically.

Matters become more complicated when there is premature adult mortality. First, the values of Λ^d, Λ^* and Λ^a depend both on $s_t \in \{1,2,3\}$ and on κ_{t+1}. Second, a separate phase diagram is needed for each pair of states in periods t and $t+1$. For example, the offspring of a two-parent family in period t all attain the λ_{t+1} corresponding to $\Lambda_t(1)$, but not all their offspring are raised in two-parent families. In principle, therefore, a phase diagram is required for each of the cases in the set $S_t \times S_{t+1}$. The ensuing heterogeneity and its consequences for the system as whole will now be explored in greater detail.

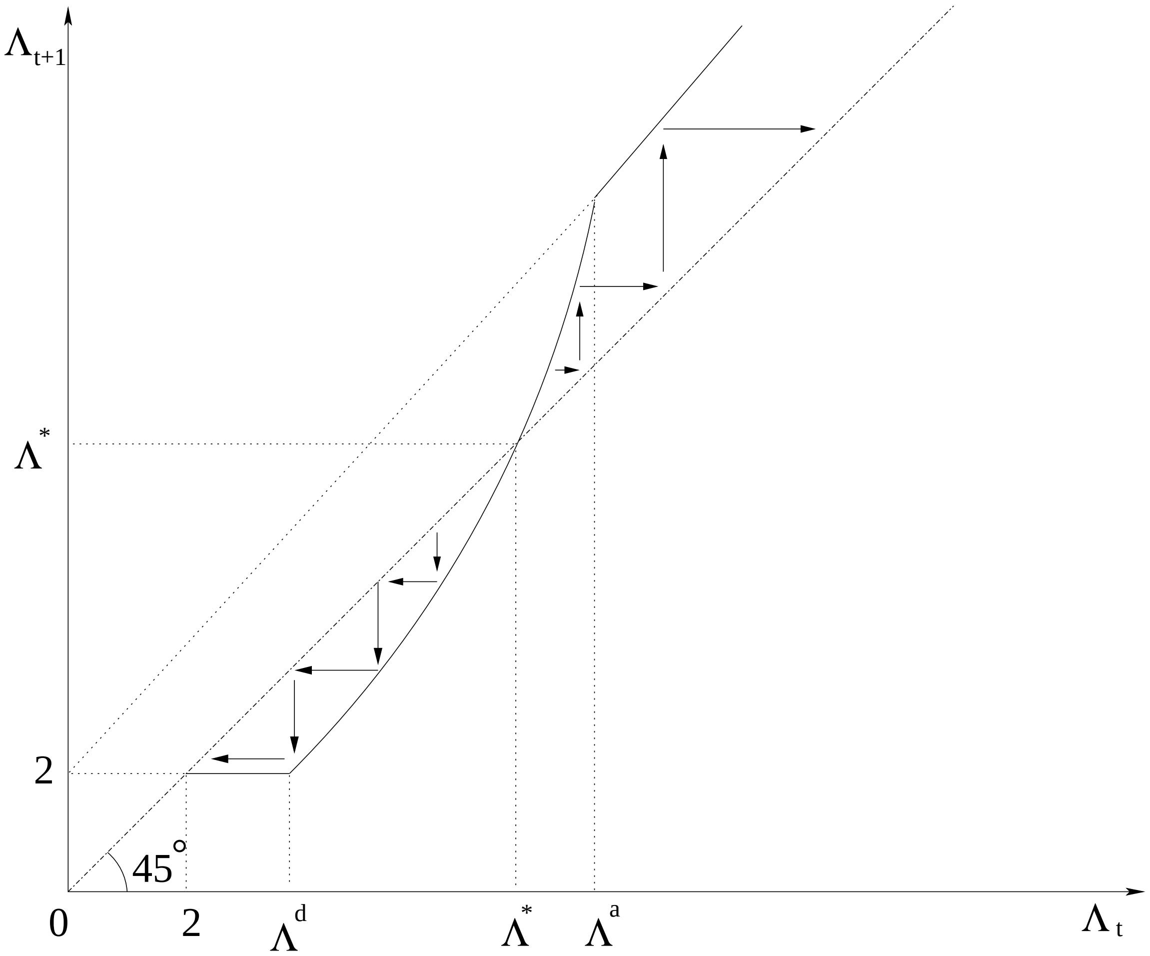

Figure 1: The phase diagram in the absence of premature adult mortality.

3 Disease, Increasing Inequality and Economic Collapse

3.1 Steady States

The process by which the onset of a disease like AIDS leads to economic collapse can be described as follows: At the start of period $t = 0$, a society of homogeneous two-parent families, each with adult human capital endowment $2\lambda_0$, is suddenly assailed by some fatal disease. Immediately after their children are born, all adults learn whether they are infected with the disease, and the survivors then choose $\left(c_0^0(s_0), e_0^0(s_0)\right)$ for $s_0 = 1,2,3$. We are interested in the question: how does the outbreak of the disease affect the subsequent development of the society? Children who are left as unsupported orphans $(s_0 = 4)$ fall at once into the poverty trap. Assumption 7 also implies that $e_t^0\left(2\xi, 1\right) = 0\ \forall t$: even if both parents survive but have been orphans in childhood, they cannot afford to send their children to school. In the absence of support, therefore, all orphans fall into the poverty trap, and their succeeding lineage remains there. In order to discover what happens to the rest, we introduce the critical value function $\lambda^*(s, \kappa_t)$ for $s \in \{1,2,3\}$, $n_{t+1} = n_t$, $\forall t$ and $\kappa_t = \kappa$, $\forall t$ defined by:

$$\lambda^*(s,\kappa) = z(s)\, f\left(e^0(\Lambda^*(s), s, \kappa)\right)\Lambda^*(s) + 1 \tag{11}$$

where $\Lambda^*(1) = 2\lambda^*(1)$, $\Lambda^*(2) = \Lambda^*(3) = \lambda^*(2) = \lambda^*(3)$, and κ is a sufficient statistic of premature adult mortality in the steady state. $\lambda^*(s,\kappa)$ is the steady-state human capital associated with a particular state s, that is, in any pair of generations, parent(s) and offspring share the same state.

In order to establish the relationship between $\lambda^*(s,\kappa)$ and $e^0(\Lambda^*(s), s, \kappa)$, we differentiate (11) totally and rearrange terms with respect to κ and obtain:

$$\frac{d\lambda^*}{d\kappa} = \frac{(3-s)z(s)\lambda^* f'(e^0)\frac{\partial e^0}{\partial \kappa}}{\frac{1}{\lambda^*} - (3-s)z(s)f'(e^0)\frac{\partial e^0}{\partial \lambda^*} - \frac{1}{\lambda^*}(3-s)\,z(s)\,f(e^0)} \tag{12}$$

An increase in premature adult mortality increases $\lambda^*(s,\kappa)$, $s = 1,2,3$. To be precise, we have

Lemma 2

$(i)\quad \partial\lambda^*(s,\kappa)/\partial\kappa < 0, \quad s = 1,2,3$

$(ii)\quad \lambda^*(1,\kappa) \leq \lambda^*(2,\kappa) = \lambda^*(3,\kappa)$

Proof :

Observe from Figure 1 that the slope of the right hand side of equation (11) is larger than 1 at λ^*. Hence,

$$\frac{\partial}{\partial\lambda}((3-s)z(s)f(e^0(\Lambda^*(s),s,\kappa))\lambda^*(s)) > 1$$

which implies

$$(3-s)z(s)f'(e^0)\frac{\partial e^0}{\partial\lambda^*} > 1-(3-s)z(s)f(e^0) \geq \frac{1}{\lambda^*}\left\{1-(3-s)z(s)f(e^0)\right\}.$$

Hence, the denominator in (12) is negative. According to the third part of Lemma 1, the numerator in (12) is positive, which proves the first claim. To establish the second claim, observe that, starting in any period t,

$$\begin{aligned}\lambda^*(1,\kappa) &= z(1)f(e^0(\Lambda^*,1,\kappa)\cdot\Lambda^*(1,\kappa)+1 \geq \lambda_{t+1}(2,\kappa)\\ &= z(2)f(e^0(\Lambda^*(2),2,\kappa)\cdot\Lambda^*(1,\kappa)/2+1\end{aligned}$$

by virtue of assumption 2 and the first part of lemma 1. The second claim then follows at once. ■

The first part of lemma 2 implies that an increase in premature adult mortality may cause a group that was earlier enjoying self-sustaining growth to fall into the poverty trap. The second part implies that single-parent families need higher individual levels of human capital than two-parent ones to escape the trap, so that an increase in premature adult mortality also increases the share falling into the poverty trap by increasing the proportion of one-parent families.

3.2 Short-Run Dynamics

We now turn to the short-run dynamics following a shock represented by $\kappa_t = \kappa < 1$ for all $t \geq 0$. We denote by P_t the fraction of the population of adults whose human capital is at most unity in period t. Similarly, R_t denotes the fraction of individuals that possess at least $\lambda^*(2,\kappa)$. Note that $P_t + R_t \leq 1$. We obtain the following results:

Lemma 3

Suppose that $\lambda_0 > \lambda^*(1,1)$.

(i) If $\lambda_0 \geq \lambda^*(2,\kappa)$, *then*

$P_1 = \pi(4), R_1 = 1 - \pi(4)$

(ii) If $\lambda^*(2,\kappa) > \lambda_0 \geq \lambda^*(1,\kappa)$, *then*

$P_1 \geq \pi(4), R_1 \leq \pi(1)$

(iii) If $\lambda^*(1,\kappa) > \lambda_0$, *then*

$P_1 \geq \pi(4), R_1 = 0$

The three claims immediately follow from our preceding discussion. In case (i), families with at least one surviving adult will continue to enjoy self-sustaining growth, although one-parent households will henceforth experience growth at a lower rate if $z(1) > z(2)/2$, even if $e_0^0(2) = 1$. This adverse effect will be reinforced if e^0 falls following the shock. The resulting inequality among families with adults will be propagated into the future, with further differentiation arising both from the transmission factor $z(s)$, and from future differences in $e_t^0(\cdot)$ among them. In case (ii), only families with two adults will continue to experience self-sustaining growth, whereas all the others will descend into the poverty trap. Thereafter, the pattern of progressive differentiation described in case (i) will also take hold here. In case (iii), all families begin to descend into poverty immediately.

3.3 Long-Run Dynamics

The preceding discussion yields straightforward implications for long-run dynamics, which are summarized in the next proposition.

Proposition 1

If $\kappa_t < 1$ *for all* $t \geq 0$*, then:*

(i) $P_t \geq P_{t-1} + \pi_{t-1}(4)(1 - P_{t-1}), \quad t \geq 1$

(ii) $\lim_{t\to\infty} P_t = 1$

Note that part (i) of proposition 1 holds as an equality if $\lambda_0 \geq \lambda^*(2,1)$. Proposition 1 indicates that the share of uneducated families grows over time until, in the limit, the whole population is in backwardness. Not only do some adults suffer sickness and early death, but the whole society descends progressively into the poverty trap. This dramatic implication leads one to ask what social arrangements can be made to deal with this danger. One answer is to pool the risks which we take up in section 5.

3.4 Inequality

The preceding sections illustrate that the epidemic disease introduces and exacerbates income inequality if the society is initially homogeneous. However, as the epidemic persists, inequality, measured in any standard way, declines as the whole society descends progressively into the poverty trap. AIDS initially creates, but then eliminates inequalities as the disease destroys human capital and its transmission among generations. The simple point of this discussion is that inequality concerns in the presence of an epidemic disease must be considered with caution. A decline in inequality does not reflect welfare gains if a society is concerned about both growth and equity.

4 An Example

In this section we provide a detailed analysis of an example in order to illustrate the most important results from our household model and how the steady state associated with a particular household state $s_t = (1,2,3)$ depends on preferences, premature mortality, discounting, the characteristics of child labor and child consumption, and the productivity of human capital. The example also reveals that the existence of a unique, unstable steady state cannot be taken for granted, even when the model does not take its most general form.

4.1 Household decisions

We work with the following functional forms:

$$f(e_t) = e_t$$

$$u(c_t) = \begin{cases} c_t & \text{if} \quad c_t \geq c^{\min} \\ -\infty & \text{otherwise} \end{cases}$$

$$v(\lambda_{t+1}) = \delta \ln(\lambda_{t+1} + \zeta) \;\text{ with }\; 0 < \delta < 1$$

We further simplify the analysis by assuming that $z(1) = \frac{z(2)}{2} \equiv \bar{z}$.

To examine the household's decisions, we form the Lagrangian for $s_t = 1$ and $s_t = 2$:

$$\begin{aligned} \mathcal{L}(s_t) \;&=\; (3-s_t)\,c_t + (3-s_t)n_t\kappa_{t+1}\delta\,\{\ln(2\bar{z}\,e_t\,\lambda_t + 1 + \zeta)\} \\ &\quad + \mu\{\alpha((3-s_t)\lambda_t + n_t\gamma) - (3 - s_t + n_t\,\beta)c_t - n_t\,\alpha\gamma e_t\} \end{aligned}$$

The first-order conditions are:

$$\frac{\partial \mathcal{L}}{\partial c_t} = (3-s_t) - \big(3 - s_t + n_t\beta\big)\,\mu \leq 0, \quad c_t \geq c^{\min} \quad \text{complementarily}$$
$$\frac{\partial \mathcal{L}}{\partial e_t} = \frac{(3-s_t)n_t\kappa_{t+1}\delta 2\bar{z}\lambda_t}{2\bar{z}\,e_t\,\lambda_t + 1 + \zeta} - \mu\alpha n_t\gamma \leq 0, \quad e_t \geq 0 \quad \text{complementarily}$$

Assuming an interior solution, solving for μ yields

$$\mu = \frac{3 - s_t}{3 - s_t + n_t\beta}$$

Thus, we obtain the optimal choices $e_t^0(s_t)$ as follows:

$$e_t^0(s_t) = \frac{2\kappa_{t+1}\delta\bar{z}\lambda_t(3 - s_t + n_t\beta) - \alpha\gamma(1+\zeta)}{2\alpha\gamma\bar{z}\lambda_t}, \;\; s_t = 1,2 \tag{13}$$

We immediately observe that $e_t^0(1) > e_t^0(2)$ as long as an interior solution holds for $s_t = 2$. Obviously, $e_t^0(s_t)$ is set to zero if (13) yields a negative number, and it is set to unity if (13) yields a number larger than 1. The budget constraint yields the corresponding interior solution for an adult's consumption:

$$c_t^0(s_t) = \frac{-2\kappa_{t+1}\delta\bar{z}\lambda_t n_t(3 - s_t + n_t\beta) + \alpha\gamma n_t(1+\zeta) + 2\alpha\lambda_t\bar{z}\big((3-s_t)\lambda_t + n_t\gamma\big)}{(3 - s_t + n_t\beta)2\bar{z}\lambda_t} \tag{14}$$

We summarize the properties of the optimal choices in the following proposition.

Proposition 2

Suppose $\zeta > -1$. Then:

(i) $e_t^0(1) \geq e_t^0(2)$

(ii) $e^0(s_t) := \lim_{\lambda_t \to \infty} e_t^0(s_t) = \min\left\{\frac{\delta\kappa(3 - s_t + n\beta)}{\alpha\gamma}, 1\right\}$,
where $\lim_{t\to\infty}\kappa_{t+1} = \kappa$ *and* $n_t = n \; \forall t$

(iii) *If* $e^0(1) < 1$, *then* $e^0(1) > e^0(2)$

(iv) $\frac{\partial e_t^0(s_t)}{\partial\lambda_t} > 0$ *for* $0 < e_t^0(s_t) < 1$

(v) $\frac{\partial c_t^0(s_t)}{\partial\lambda_t} > 0$ *for all* $\lambda_t > \hat{\lambda} \equiv \sqrt{\frac{\gamma(1+\zeta)}{2\bar{z}(3-s_t)}}$

As long as $\lambda_t > \hat{\lambda}$, therefore, the example fulfills all the conditions of the general household model, as set out in section 2.1.1.

4.2 Steady states

We now calculate the steady-state value of λ_t associated with positive education levels. For this purpose, we require a stationary mortality profile and stationary fertility: $\kappa_t = \kappa$, $n_t = n \, \forall t$. The steady state is given by:

$$\lambda^*(s_t,\kappa) = 2\bar{z}\lambda^* \frac{(3-s_t+n\beta)\,2\kappa\delta\bar{z}\lambda^* - \alpha\gamma(1+\zeta)}{2\alpha\gamma\bar{z}\lambda^*} + 1 \;\; s_t = 1,2$$

Solving for $\lambda^*(\cdot)$ yields:

Corollary 1

Suppose $\zeta > 0$ *and* $\alpha\gamma(\zeta+1) > (3-s_t+n\beta)2\delta\kappa\bar{z}$. *Then for* $s_t = 1,2$, *there exists a unique steady state* $\lambda^*(s_t,\kappa) > 1$ *which is associated with a positive level of education whereby:*

$$\lambda^*(s_t,\kappa) = \frac{\alpha\gamma\zeta}{(3-s_t+n\beta)2\delta\kappa\bar{z} - \alpha\gamma}$$

Note that $\partial\lambda^*/\partial\kappa < 0$: lower premature mortality among adults is associated with a lower steady-state value of λ. Thus, the steady state has the following properties, which accord with intuition:

Corollary 2

Suppose $\zeta > 0$ *and* $\alpha\gamma(\zeta+1) > (3-s_t+n\beta)2\delta\kappa\bar{z}$. *Then,*

(i) $\dfrac{\partial\lambda^*(s_t,\kappa)}{\partial\kappa} < 0$

(ii) $\lambda^*(2,\kappa) > \lambda^*(1,\kappa)$

(iii) *there exists a* $\hat{\kappa} \in (0,1)$ *such that* $\lim_{\kappa\to\hat{\kappa}} \lambda^*\left(s_t,\hat{\kappa}\right) = \infty$

5 Pooling

The prevailing form of social organization has a potentially important influence on how the economic system copes with premature adult mortality. We can distinguish between two extreme types. First, there is the family as the nucleus of society (the nuclear family), which is essentially the preceding set-up of our model. Parents are solely responsible for their own children, so that the fortunes of children depend entirely on their natural parents' health status and human capital (or income).

The second involves collective (or pooling) arrangements. We shall say that pooling occurs when a subset of society, be it a region, a city, a tribe, even a very large extended family, pools its resources. It is widely observed that in Africa, for example, orphans are often taken in by, and rotated among, relatives. It is sometimes claimed that the relatives also treat such children as if they were their own; but this goes too far – for instance, Case, Paxson and Ableidinger (2002) show that the schooling of orphans depends heavily on how closely they are related to the adoptive household head. To examine this arrangement, we allow the society to be pooled completely, that is to say, all surviving adults in the society take on joint responsibility for all children in their group. For simplicity, we assume that within each generation, all adults and children are treated identically. Pooling of the society suffices to diversify completely the idiosyncratic mortality risk, and the pooled group faces only the aggregate risk, as summarized by κ.[6] Pooling introduces the need for some additional notation: it will be denoted by the family state $s_t = 0$.

5.1 The household's behavior under pooling

By assumption 5, each couple produces n_t surviving children in period t; but not all of the adults themselves survive to rear their offspring. Under complete pooling, the children are effectively reared collectively, in the sense that each surviving 'pair' of adults raises not n_t, but

[6]We could also consider partial pooling as an intermediate case where a sufficiently large subset of the society – subintervals in our model – are pooled. Partial pooling already suffices to achieve complete insurance against idiosyncratic risks.

$$n_t(0) = \frac{n_t}{\kappa_t} = \frac{2n_t}{1+\pi_t(1)-\pi_t(4)} \tag{15}$$

children. In effect, the burden of premature adult mortality is borne equally by all surviving members of a generation. The budget line of a representative 'pair' is

$$[2+(n_t/\kappa_t)\beta]c_t(0)+\alpha(n_t/\kappa_t)\gamma e_t(0) = \alpha[2\lambda_t+(n_t/\kappa_t)\gamma], \tag{16}$$

a comparison of which with (5) reveals that, relative to an otherwise identical two-parent nuclear family, the presence of premature adult mortality implies, first, a lower relative price of current consumption, and second, a lower level of full income, measured in units of an adult's consumption, so long as $\beta > \gamma$. On this score, therefore, a rise in such mortality works to reduce education, relative to the two-parent, nuclear family. Pursuing this point further, it is also seen that by setting κ_t equal to 1 and 1/2, (16) specializes to the cases $s_t = 1$ and $s_t = 2$, respectively, in (5). As we will now see, however, pooling is not necessarily an intermediate case between one- and two-parent nuclear families whenever $\kappa_t \in [1/2, 1]$.

One can think of the pooling arrangement as a representative two-parent family looking after n_t/κ_t children, as opposed to either one or two parents looking after n_t, as analyzed in sections 2.1 and 2.2. In order to bring out this point, the transmission factor under pooling is written as $z(0,\kappa_t)$, where we use the state 0 to denote pooling. If there is no premature adult mortality, pooling is never called into operation, so that $z(0,1) = z(1)$. If $\kappa_t = 1/2$, the question arises whether two parents can impart a higher potential to each of $2n_t$ children than one parent (of either sex) to n_t; in keeping with assumption 2, they could hardly do worse. We therefore introduce:

Assumption 8. For any given n_t, $z(0,\kappa_t)$ is a non-decreasing, continuous and differentiable function of κ_t; it also satisfies $z(0,1/2) \geq z(2)/2$ and $z(0,1) = z(1)$.

Hence, the formation of human capital under pooling is given by:

$$\lambda_{t+1} = 2z(0,\kappa_t)f(e_t)\lambda_t + 1 \tag{17}$$

Turning to preferences, let the 'couple' display the same degree of altruism towards natural and adopted children alike, which implies that all children will be treated in the same way. We have

$$EU_t(0) = 2[u(c_t(0)) + n_t(\kappa_{t+1}/\kappa_t)v(2z(0,\kappa_t)f(e_t)\lambda_t + 1)]. \tag{18}$$

Since $\kappa_t < 1$, a comparison of (18) with (8) reveals that there is a greater weight on the childrens' future human capital in the former (pooling) than in the latter (in which the weights are identical for one- and two-parent families). The assumption that the adults view all children in their care with equal altruism therefore tugs in the opposite direction to that of the price and income effects where investment in education is concerned.

The steady-state value of human capital in the pooling case satisfies

$$\lambda^*(0,\kappa) = 2z(0,\kappa)f(e^0(2\lambda^*(0,\kappa),0,\kappa)) \cdot \lambda^*(0,\kappa)) + 1. \tag{19}$$

Were it not for the force of equal altruism towards all children under pooling, the argument in part (ii) of lemma 2 and assumption 8 would yield the following result: $\lambda^*(1,\kappa) \leq \lambda^*(0,\kappa) \leq \lambda^*(2,\kappa)$ for all $\kappa \in [1/2,1]$. As it is, an alternative assumption will suffice to ensure that it indeed holds.

Lemma 4

Suppose, by social convention, that all children must be treated identically, but surviving adults value only the future human capital attained by their natural children. Then

$\lambda^*(1,\kappa) \leq \lambda^*(0,\kappa) \leq \lambda^*(2,\kappa)$ *for all* $\kappa \in [1/2,1]$.

5.2 The virtues and drawbacks of pooling

Since pooling is a form of social insurance against premature mortality, it is interesting to ask whether this form of organization is better able to withstand a shock than one based on the nuclear family. The answer turns out to depend on the initial level of human capital.

Proposition 3

Suppose the disease breaks out in period 0, with resulting mortality represented by κ (< 1).

(i) If $\lambda^*(0,\kappa) < \lambda_0$*, no collapse will occur.*

(ii) If $\lambda^*(0,\kappa) > \lambda_0$*, the entire group begins an immediate descent into the poverty trap.*

The proof of proposition 2 is straightforward. The outcome in part (i) stands in contrast to that in part (ii) of proposition 1. Under pooling, moreover, perfect equality is maintained within each generation. The drawback arises when the change in mortality is so large that the initial level of human capital no longer lies above the critical level in the newly prevailing disease environment. Equality of treatment then pulls everyone down together, whereas in a nuclear family structure with $\lambda^*(1,\kappa) < \lambda_0 < \lambda^*(0,\kappa)$, two-parent families will continue to experience growth. This latter fact plays a very important role when policy interventions are possible, for two-parent families comprise the main tax base in a nuclear family setting.

6 Conclusions

The central conclusion of this paper is that the weakening of the mechanism through which human capital is transmitted and accumulated across generations through epidemic diseases becomes apparent only after a lag, and it is progressively cumulative in its effects. An economy may collapse because of epidemic diseases.

The current paper is focused on the feedbacks from premature mortality to education, the formation of human capital and output. The current framework might offer some useful directions for future research. Introducing physical capital and savings for its accumulation would tend to weaken the link between the course of the epidemic and economic growth as the depreciation of physical capital is not affected by the disease. In turn, physical capital diverts resources from human capital formation and may tend to aggravate the decline of education when a society is assailed by an epidemic. Whether the presence of physical capital tends to retard or to accelerate a collapse is an important avenue for further research. Moreover, we must be concerned about negative supply side effects in the education sector. An epidemic disease such as AIDS may tend to reduce the supply of teachers in a higher proportion than children which may undermine the quality of education, which in turn, would accelerate a collapse.

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