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Health shocks and natural resource management: Evidence from Western Kenya ☆

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ABSTRACT

Poverty and altered planning horizons brought on by the HIV/AIDS epidemic can change individual discount rates, altering incentives to conserve natural resources. Using longitudinal household survey data from Western Kenya, we estimate the effects of health status on investments in soil quality, as indicated by households' agricultural land fallowing decisions. We first show that this effect is theoretically ambiguous: while health improvements lower discount rates and thus increase incentives to conserve natural resources, they also increase labor productivity and make it more likely that households can engage in labor-intensive resource extraction activities. We find that household size and composition are predictors of whether the effect of health improvements on discount rates dominates the productivity effect, or vice-versa. Since households with more and younger members are better able to reallocate labor to cope with productivity shocks, the discount rate effect dominates for these households and health improvements lead to greater levels of conservation. In smaller families with less substitutable labor, the productivity effect dominates and health improvements lead to greater environmental degradation

Introduction

Throughout the developing world, natural resources are an important input to household production and welfare. Indeed, for many, natural capital stocks account for a sizable fraction of aggregate household income and wealth, even when property rights over them are poorly defined. Of course, the use of these natural resources in household production can also have far reaching, and often negative, consequences. While clearing forests may provide essential fuel and other raw materials to households in poor upland villages, it may also threaten local biodiversity, downstream water quality,

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and climate worldwide. The flashpoint in the development debate often centers on the tension between the joint goals of poverty reduction and environmental quality, but it is not entirely clear that these goals are always contradictory. In some dimensions and in a shorter time horizon there may be tradeoffs but, in the longer term, environmental degradation is a threat particularly to the poor who depend more heavily on intact ecosystem resources not only for daily services such as water, firewood building materials, fibers, and protein but also as capital that can be harvested in times of need. This paper is sheds light on potential tensions between environmental and development goals by examining the relationship between health shocks and the management of environmental resources.

Health shocks are an opportune lens through which to view this problem for several reasons. First, many of the environmental hot spots in the world are located in impoverished regions where individuals live under the constant threat of serious illness. Second, the environmental impacts of health shocks are theoretically ambiguous. Resource extraction and the activities that use these resources for production tend to be labor intensive, suggesting greater environmental conservation in the face of significant morbidity. On the other hand, health may also affect discount rates households use when making tradeoffs over time. Altered planning horizons due to shortened life expectancies can undermine incentives to conserve, while increased medical costs and caloric needs can force households to liquidate capital, both physical and natural. As morbidity and mortality also decrease income, households may increasingly turn to less sustainable activities such as hunting, logging, and charcoal-making for subsistence needs, precipitating environmental degradation.[1] Lastly, examining changes in natural resource management stemming from unexpected changes in household characteristics provides an opportunity to deepen our understanding of the mechanisms through which poor households rely on the natural environment to improve their well-being.

In this paper, we develop a simple model of labor allocation, which depends upon health. Households divide their time between leisure and agricultural labor. Natural capital is an input to agricultural production and its use today limits its availability in the future. The key feature of this model is that negative health shocks simultaneously reduce labor productivity and shrink planning horizons.[2] As such, the overall impact of health shocks will depend on the relative magnitudes of the two opposing effects. We then empirically examine this theoretical ambiguity by estimating the effect of treatment for HIV/AIDS on investment in soil quality as measured by agricultural rotations of fallow land using a novel household dataset from Kenya. Two key assumptions are critical for our identification strategy. The first is that improvements in health due to treatment will go in the opposite direction of, or “undo”, the theorized impacts of a health shock; thus, identifying treatment effects can inform us of household behavior under the health shock that preceded treatment. Second, we assume that the availability and effects of treatment are generally unanticipated, such that behavioral changes are indeed driven by a health ‘shock’ rather than planned for in advance. The basis for these assumptions is described in the Treatment of HIV/AIDS with antiretroviral therapy section.

Of course, understanding the interactions between morbidity and mortality caused by HIV/AIDS and the way natural resources are managed has value in its own right, not only by shedding light on broader tensions between poverty, time preferences, and the environment. Livelihoods in many regions that are heavily affected by HIV/AIDS are highly dependent on forests, agriculture, and/or fishing. Moreover, food security is an especially grave concern in this context since AIDS is known to exacerbate malnutrition through its detrimental effect on the immune system and nutrient absorption, while malnutrition in turn increases susceptibility to HIV infection (Loevinsohn and Gillespie, 2003; Semba and Tang, 1999). Differential access to fertile soil or healthy fish stocks can thus play a major role both in disease prevention and treatment efficacy (Piwoz and Preble, 2000). Our focus on investments in soil fertility through fallow plot rotations is especially attractive because the returns to fallow are relatively high in our region of study (Sanchez, 1999) and the incentives to invest are not contaminated by issues of common property.

Our results suggest that health shocks do, in fact, alter incentives to conserve natural resources by influencing the costs of resource extraction as well as planning horizons. In particular, we find that a household’s size and age composition are key predictors of whether the productivity effect dominates the discount rate effect, or vice-versa. Smaller and older households leave less land fallow as sick household members become healthier with effective treatment, while larger and younger households leave more land fallow as they become healthier. Since households with more members and younger adult labor are better able to reallocate labor to cope with the productivity shock associated with sick household members, they can act upon their labor-intensive desire to draw down their natural capital stock when a household member is ill. Health improvements due to treatment then lead to greater levels of conservation through increased fallowing. In contrast, smaller households with less substitutable labor are ill-equipped to act upon their desires to expend natural capital when a household member is ill, so the productivity impact dominates the discount rate impact and we see little change in fallowing decisions in response to illness. Our results are robust to a wide range of specifications in which we address the possible endogeneity of household size by controlling for key household characteristics. They also remain largely unaffected by the characteristics of the patient within the household.

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[1] The effect of income shocks on investment behavior in developing countries has received considerable attention in the literature. (See, for example, Strauss and Thomas, 1995; Kochar, 1995; and Jacoby and Skoufias, 1997). These studies highlight the sensitivity of investment decisions to credit and insurance market imperfections. Since health shocks are likely to be less insurable than pure income shocks, we expect the investment impacts to be especially pronounced in this setting.

[2] A number of studies have documented the impacts of poor health on agricultural productivity (e.g. Deolalikar, 1988; and Pitt et al. 1990).

This paper is organized as follows: the Conceptual framework section presents our conceptual framework for assessing the differing effects of health shocks on natural resource management. The Background and data section provides background on the HIV/AIDS treatment intervention that we study, land fallowing in our study region, and the household survey data. In the Empirical strategy section, we describe our strategy for estimating the impact of treatment on the decision to fallow land. Results are presented in the Results section and the final section concludes.

Conceptual framework

In this section, we develop a conceptual model to illustrate the competing influences of health shocks on natural resource management. We begin with a simple model of unitary household behavior in autarky. Utility is simply a function of agricultural production and leisure $U(X, L)$, where agricultural production depends on the use of two inputs: labor l and natural capital k. Recognizing that not all labor is equally productive, we introduce the function $h(\Phi,N)$, such that $h(\Phi,N)l$ can be interpreted as the amount of 'effective' household labor applied to agriculture. This function depends on the health status of the household, as indexed by Φ, and on household size, N, where h is a concave function increasing in both Φ and N and health and size are gross substitutes for one another.[3] Importantly, our modeling framework treats household size as exogenous vis-à-vis health shocks, a contention that we will validate with our data. Thus, assuming a Cobb–Douglas production function, agricultural production is expressed as: $(h(\Phi,N)l)^{\alpha}k^{1-\alpha}$

An important feature of our research question relates to the intertemporal tradeoffs associated with natural capital extraction. Since natural capital extraction reduces the amount of capital available in the future, we need to capture this cost. To simplify the analysis we treat natural capital as a non-renewable resource. Given an initial natural capital endowment of $\bar{k}$, the amount of natural capital available in the 'future' period of a two-period model is expressed as $\bar{k}-k$.[4] Looking ahead to our empirical work, we will view land fallowing as a decision to set $k \le 0$ by limiting agricultural production in the current period. Importantly, future period utility is discounted by $\delta(\Phi)$, where δ is a pure rate of time preference that is increasing in the health status of the household to capture the notion of shrinking planning horizons as the result of serious illness.[5]

The household maximization problem can be represented as: $\max_{l,k} \quad U(X,L)+\delta(\Phi)[\bar{k}-k]$, where $X=(h(\Phi,N)l)^{\alpha}k^{1-\alpha}$ and $T=L+l$. In essence, households are maximizing agricultural production through the application of labor and natural capital inputs, where the cost of labor is measured in foregone leisure and the cost of natural capital is measured in terms of its diminution of stocks for the future. Given this simple framework and assuming additively separable utility,[6] we can derive the first order conditions that define an interior maximum:

$$\frac{\partial U}{\partial X}\alpha(hl)^{\alpha-1}k^{1-\alpha}h-\frac{\partial U}{\partial L}=0 \qquad (1)$$

$$\frac{\partial U}{\partial X}(hl)^{\alpha}(1-\alpha)k^{-\alpha}-\delta=0 \qquad (2)$$

As one would expect, Eqs. (1) and (2) suggest that input levels will be chosen such that the value marginal product equals marginal cost as transformed through the utility function. Combining (1) and (2) and applying the implicit function theorem allows us to examine the relationship of interest:

$$\frac{dk}{d\Phi}=-\frac{\frac{\partial^2 U}{\partial L\partial X}\alpha(hl)^{\alpha-1}k^{1-\alpha}\frac{\partial h}{\partial \Phi}l\frac{1-\alpha}{\alpha}\frac{l}{k}-\frac{\partial \delta}{\partial \Phi}}{\frac{\partial^2 U}{\partial L\partial X}(hl)^{\alpha}(1-\alpha)k^{-\alpha}\frac{1-\alpha}{\alpha}\frac{l}{k}-\frac{\partial U}{\partial L}\frac{1-\alpha}{\alpha}\frac{l}{k^2}} \qquad (3)$$

The concavity assumptions ensure that the sign of the denominator is negative, so the influence of health on natural capital extraction rates, and conversely on resource conservation, will depend on the sign of the numerator. An interior solution will also guarantee a minimum degree of complementarity between leisure and consumption in the utility function and can be used to bound the numerator. Substituting in the first-order-conditions (Eqs. (1) and (2)) and algebraic

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[3] In this framework, the productivity impact of health on natural capital extraction occurs indirectly through its impact on agricultural productivity. A model that included a direct productivity impact on the extraction process would yield similar insights, but would depend on the relative impacts on the productivity of extraction labor versus agricultural labor.

[4] The only important feature for our analysis is that current extraction has future consequences whose welfare impacts depend on time preferences. Modeling household decisions in a formal dynamic model of a renewable resource yields conceptually similar first-order-conditions, but makes the analysis of health impacts more complex with little added insight.

[5] Our assumption that the impact of health on the discount rate is independent of household characteristics is supported by our empirical results, which find fallow decisions are insensitive to gender and the relative standing of the patient within the household. Moreover, if the impact of health on the discount effect were decreasing in family size, as one might expect if the voice of one sick household member was drowned out by many, this would simply bias our empirical work toward finding no differences between large and small households since small households would be unable to mine the soil in the face of the health shock and large households would have limited desire to do so.

[6] The assumption of additive separability implies that the marginal utility of leisure is independent of household income in our model. Since ART is provided at zero financial cost to patients we do not expect their consumption to directly impact desired leisure. On the other hand, treatment could indirectly impact the marginal utility from leisure if households view the benefits from treatment as a permanent income shock. If this were the case, we would also expect households to move toward more capital-intensive agricultural activities. We find no impact of AIDS treatment on seed or fertilizer use (unreported results), suggesting that the separability assumption is reasonable.

manipulation yields the following expression, which characterizes a threshold for the effect of health shocks on resource conservation:

$$\alpha\eta_h = (1-\alpha)\eta_\delta, \tag{4}$$

where η_h is the elasticity of the effective labor function and $\eta_\delta$is the elasticity of the discount function, both with respect to health.[7] At the threshold, we find that the output elasticity of labor multiplied by the elasticity of effective labor with respect to health is equal to the output elasticity of natural capital multiplied by the elasticity of the discount function which weights the value of future natural capital stocks. Above this threshold, negative health shocks lead to greater resource conservation and below the converse is true.

Since the elasticity of effective labor with respect to health depends on household size, Eq. (4) can also be interpreted as one that implicitly defines a threshold household size N^*. For households larger than N^*, the left-hand-side is smaller than the right-hand-side, suggesting that negative health shocks will lead to greater resource extraction. Conversely, households smaller than N^* will conserve more resources in the face of a negative health shock. Thus, in our empirical model we expect larger households to reduce fallowing during periods of illness and to increase conservation once patients are recovered.

The intuition behind this result is straightforward. A negative health shock reduces planning horizons for all households, which in turn increases incentives to draw down natural capital stocks through increased agricultural activity. In our autarkic framework, however, only households with a large labor endowment are able to reallocate labor in order to expand agricultural plantings and thus mine the soil. While smaller households would prefer to draw down capital stocks, they do not have enough household labor to do so. As will be explained in the Empirical strategy section, we will exploit this response heterogeneity across households of differing size in our empirical work to identify the distinct channels through which health influences natural resource management decisions.

Background and data

In this section, we provide a brief review of the literature on treatment of HIV/AIDS, land fallowing in Kenya, and then an overview of the household survey data used in our empirical analysis.

Treatment of HIV/AIDS with antiretroviral therapy

Once infected with HIV, the ability of individuals to fight infection is eroded since the virus attacks and destroys white blood cells and eventually this leads to AIDS. In sub-Saharan Africa, most HIV transmission among adults occurs through heterosexual intercourse (UNAIDS, 2010). Soon after transmission, infected individuals enter a clinical latent period of many years during which health status declines gradually with few or no symptoms. The median time from infection to AIDS in east Africa is estimated to be 9.4 years (Morgan et al., 2002). During this latency period, most HIV-positive individuals are physically capable of performing all normal activities and typically unaware of their infection status. Over time, however, almost all HIV-infected individuals will experience a weakening of the immune system and progress to developing AIDS. This later stage is usually associated with substantial weight loss (wasting) and a wide range of opportunistic infections. In the absence of treatment, death usually occurs within one year after progression to AIDS (Morgan et al., 2002; Chequer et al., 1992).

Antiretroviral therapy (ART) has been proven to reduce the likelihood of opportunistic infections and prolong the life of HIV-infected individuals. Treatment is typically initiated when individuals have progressed to AIDS. After several months of treatment, patients are generally asymptomatic and have improved functional capacity. This positive impact has been documented in numerous studies in various countries and patient populations. In Haiti, patients had weight gain and improved functional capacity within one year after the initiation of ART (Koenig et al., 2004). Studies in sub-Saharan Africa have similarly shown rapid improvements in immunological outcomes of patients (Laurent et al., 2002; Coetzee et al., 2004). Rapid improvements in clinical outcomes after the initiation of treatment have also been documented for the sample of patients we study in this paper (Thirumurthy et al., 2008; Wools-Kaloustian et al., 2006). In Brazil, median survival times after developing AIDS rose to 58 months with ART (Marins et al., 2003). Similar gains in life expectancy have also been confirmed by more recent studies (Goldie et al., 2006).

While the effect of ART on the health of treated patients has been widely documented, much less is known about the broader impact that treatment interventions can have on the social and economic outcomes of patients and their families. As more data have become available, a growing literature has begun to examine the effects of HIV/AIDS as well as ART on household behavior and household structure. Of special interest to this paper are the various individual and household behavioral responses that result from ART. Perhaps one of the most well-documented patterns has been in labor supply: HIV-infected adults work significantly less as the disease progresses (Fox et al., 2004) and their labor supply increases dramatically once they gain access to ART (Thirumurthy et al., 2008; Rosen et al., 2010). Our work from the same data used in this paper has also shown that households' labor supply decisions are affected by changes in the health status of HIV-infected adults. As the adults become healthier and economically active due to ART, there are reductions in the labor supply

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[7] See appendix for derivation.

of children. Similar longitudinal evidence on what happens to children's labor supply in years prior to ART initiation has been lacking. Much of the work on household dynamics has focused on the years after adult mortality, particularly as it concerns orphans (Foster and Williamson, 2000; Beegle et al., 2010). It is important to note, however, that because our study focuses on HIV-affected households in which the HIV-infected adult has access to ART, we generally observe households in years prior to any mortality episode.

The main objective of this paper is to examine how natural resource management decisions of households are affected by the health improvements due to ART. As noted earlier, one of the key assumptions underlying our empirical strategy is that the benefits from AIDS treatment can be viewed as a positive health shock. The plausibility of this assumption depends critically on the nature of HIV diagnosis and treatment during our study period. Nearly all of the patients in our sample came to the HIV clinic at a very late stage of disease and this clinic encounter was generally the first time they learned their HIV status. To put their sickness in perspective, we examined a key indicator of HIV disease stage and immunological function, the CD4+ T-cell count (CD4 count), and found that patients entered the clinic sample with an average CD4 count of 100, while AIDS generally becomes symptomatic at around 200 and patients do not generally survive treatment at levels below 50. Thus, the pattern appears to be that patients only seek care after they become extremely ill and it is that clinic visit where they first learn that they are HIV-positive. It is also worth noting that their initial infection likely occurred 7–10 years prior, when the risks of HIV were not well known in this population and the precise time from infection to AIDS was largely beyond the patient's control. Since patients appear to suffer considerable morbidity as well as considerable economic hardship before entering treatment (Thirumurthy et al., 2008) and treatment is offered at zero financial cost to patients, it appears that they do not anticipate these benefits. Of course, one might worry about those patients that never turn up in the clinic, but a comparison of the HIV clinic enrollment data to the Kenya Demographic and Health Survey (KDHS) figures on prevalence in the clinic catchment area suggests that nearly all those infected are eventually enrolling in treatment during our study period. Insofar as there are some infected individuals that never opt for treatment, their omission from our analysis should limit the generalizability of our findings rather than bias them.

Since household agricultural decisions will depend on labor and resource constraints in the households, we also note that to our knowledge there is not much formal assistance provided to HIV-affected households in our sample other than ART and a few other medications for opportunistic infections related to HIV. In our survey data, fewer than 5% of ART households reported receiving transfers from the government or other organizations (averages in the follow-up data are not very different).[8] There is also relatively little in the way of free labor assistance.[9] While there may be changes in other household behaviors as a result of ART, our analysis aims to estimate the reduced form effect on one particular behavior related to natural resource management: land fallowing.

Land fallowing in Kenya

Land fallowing is a process where agricultural land is taken out of production and left to be taken over by weeds, grasses, and fast-growing woody plants. Soil carbon is rapidly lost during intensive cropping, but re-accumulates during fallow (Szott et al., 1999). Vegetated fallows have historically been a core component of many tropical agro-ecosystems and are an effective technique to restore soil fertility (Sanchez, 1999). Improvements in crop yields obtained through the use of fallows are directly linked to the process of biomass recycling, and recovery of soil carbon during the fallow phase can be surprisingly speedy; in some cases recoveries to native soil carbon levels have been observed after only 10 years of natural fallow (Mosier, 1998). Other benefits to fallowing include increased soil moisture retention due to accumulating organic matter, and increased micronutrient availability as tree and shrub roots penetrate the soil and subsoil.

As recently as 1997, field research showed that a majority of Kenyan farmers still used natural fallows, although in populated regions the duration of fallow periods was frequently shorter—often only two non-cropped growing seasons or less (Swinkels et al., 1997). Fallowing has been found to be particularly important for the cultivation of maize – the principal crop grown in our study area – which can rapidly drain soil of its productive capacity when cultivated continuously. Recent evidence suggests that maize-natural fallow systems can result in soil microbial C, N, and P levels 1.3 to 1.5 times higher than continuous maize production Bünemann et al. (2004). Nonetheless, the use of agricultural practices that extract vital minerals from the soil – "soil mining" – may now represent from 33% to 80% of overall farm income in Kenya (Haggblade et al., 2003). Soil fertility depletion is a matter of serious concern, and has been identified as the root cause of declining per-capita food production and hunger in Africa (Sanchez, 2002).

While subsequent sections include a more detailed discussion of our data, we highlight a few key aspects of agricultural practices and fallowing patterns in our data here. Over the time period covered by the survey, households in our sample leave 53% of land fallow in any given year, with a standard deviation of 35%. In terms of acres, on average approximately 5 ac are left fallow, with a standard deviation of 7.6 ac. During the first round of the longitudinal survey, 50% of the acres planted were being used to grow maize, the primary crop in the survey area. 31% of acreage was used for beans, peas, cowpeas, other

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[8] Households do report receiving transfers from other households, and there is some evidence that the amount of transfers received declines as the duration of time on ART increases.

[9] Hired labor is common in the study setting; our survey asked households whether or not they used hired labor on their farms in the past year but did not ask about the amount spent on hired labor or the number of hours. As we discuss in the results section, however, our results do not indicate that household were adjusting their use of hired labor to cope with changes in adult household members' health status.

Table 1
Summary statistics and comparisons across samples, at baseline.

	Census sample		ART sample		*P*-value*
	Mean	Std. dev.	Mean	Std. dev.	
Number of households	434		137		
Demographics					
Household size	6.24	2.82	6.17	2.37	0.81
Average age of household members	24.88	11.55	24.42	9.50	0.69
Age of household head	48.75	15.45	48.33	13.26	0.78
Number of family members>7	0.30	0.46	0.30	0.46	0.85
Wealth					
Radios owned by household	1.08	0.79	0.91	0.82	0.04
Education of household head					
Years of schooling	6.84	4.00	7.06	4.04	0.59
Completed primary school	0.43	0.50	0.44	0.50	0.78
Completed secondary school	0.22	0.41	0.26	0.44	0.33
Land holdings					
Total acres of land (Round 1)	8.07	10.55	6.80	9.73	0.21
Acres of land fallowed (Round 1)	3.71	6.33	4.81	8.43	0.18
Fraction of land fallowed (Round 1)	0.44	0.31	0.45	0.29	0.69

* *P*-values provided for two-tailed *t*-tests; equal variances between the two samples are not assumed.

Table 2
Comparison of household composition across survey rounds, ART sample and census sample.

	Census sample mean			ART sample mean		
	Round 1	Round 3	*P*-value*	Round 1	Round 3	*P*-value*
N	434	415		122	121	
Household size	6.24	6.37	0.51	6.17	6.13	0.89
Average age of household members	24.88	24.68	0.81	24.42	24.3	0.93
Age of household head	48.75	48.83	0.94	48.33	47.66	0.69
Household size>7	0.3	0.31	0.77	0.3	0.28	0.81
Attrition rate between survey rounds	4.4			15.0**		
	Small household			Large household		
	Round 1	Round 3		Round 1	Round 3	
Mean days on ART (SE)	6.8 (2.2)	197.2 (19.8)		1.9 (1.7)	150.4 (24.6)	
Count of HH with member on ART	11	85		2	34	

* *P*-values provided for two-tailed *t*-tests; equal variances between the two samples are not assumed.

** Attrition in the ART sample is calculated as the proportion of ART households in round 1 that remained in the round 3 sample. Since some ART households were enrolled between rounds 1 and 3, the sample sizes for the ART sample in Table 2 do not readily reflect the attrition that occurred.

pulses; while the remainder was used for vegetables and other minor crops. Tables 1 and 2, which are discussed below, provide more information on characteristics of the survey households.

Sampling strategy and survey data

This paper uses data from a longitudinal household socio-economic survey that we implemented in Western Kenya. The survey was administered in Kosirai Division, a rural region near the town of Eldoret. The Division has a population of 35,383 individuals living in 6643 households (Central Bureau of Statistics, 1999). The largest health facility in the survey area is the Mosoriot Rural Health Training Center, a government health facility that offers primary care services. It also has an HIV clinic that provides free medical care (including ART) to HIV-infected patients. The clinic began was opened in 2001 by the Academic Model Providing Access to Healthcare (AMPATH).[10] Following increased funding since late-2003, the Mosoriot HIV clinic experienced rapid growth, with many patients coming from outside Kosirai Division.[11] During this period, adequate funding has been available to provide free ART to all patients who were sick enough to require it.

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[10] AMPATH is a collaboration between the Indiana University School of Medicine and the Moi University Faculty of Health Sciences (Kenya). Descriptions of AMPATH's work in western Kenya can be found in Mamlin, Kimaiyo, Nyandiko, and Tierney (2004) and Cohen et al. (2004).

[11] For reasons including limited funding, AMPATH's clinic had very few patients during its first two years of operation. Early entrants to the HIV clinic had often progressed to AIDS at the time of their first visit. In contrast, later entrants are often in early stages of the disease and do not require ART.

We implemented three rounds of a comprehensive socio-economic survey between March 2004 and September 2006. There was an interval of roughly six months between the first two rounds, and the third round was conducted one year after the second round. Our analysis in this paper relies on data from the first and third round, since data on land fallowing were not collected in the second round. The sample includes two different groups of households that were *enrolled* in our study in round 1: 487 households chosen randomly from a census of all households in Kosirai Division without an AMPATH patient (census sample households) and 137 households with at least one known HIV-positive adult who began receiving ART at the AMPATH clinic prior to the time of the round 3 interview (ART households).[12] Our sample also includes a few additional ART households that were *enrolled* in our study in round 2. Moreover, we restrict our attention to households with non-zero landholdings, which excludes 14% of survey households (many of the land-less households resided in the main market center of the survey area and were not primarily engaged in agricultural activities). Within the ART sample, there is considerable heterogeneity in the treatment initiation date. Some patients had already been receiving treatment at the time of study enrollment. Other patients in the sample began receiving ART in between survey rounds.[13] In our empirical analysis, we identify the impact of ART on fallow decisions using variation in both the timing of treatment initiation in our sample and the relative timing of interviews in each round. As we discuss in the next section, we use the data from the census sample households to control for a range of confounding factors that would influence our interpretation of the longitudinal data for behavior in ART households.

The survey included detailed questions about demographic characteristics, health, agriculture, and labor supply. Teams of male and female enumerators typically interviewed the household head and spouse separately. For many of the AMPATH patients who resided outside Kosirai Division and too far away to be visited at home, we conducted interviews at the clinic in Mosoriot itself.

In this paper, our principal focus is on land fallowing decisions. In the survey area, maize planting decisions are typically made during the months of February through April. The first round of data collection, which occurred between March and August 2004, provides us with data on acres fallowed for the 2003 agricultural season, while the round of data collection that occurred between March and September 2006 provides us with data for 2006 as well as recall data for the intervening years of 2004 and 2005.

Empirical strategy

Since our model and its predictions are based on household responses to changes in health, we begin our analysis by confirming that time on ART does indeed translate into health improvements for our study population. In particular, we examine changes in patient CD4 cell counts – an indicator of immune system function – and body mass index (BMI) – a well-known indicator of short-term health for patients with AIDS (WHO, 1995) – by estimating the following equation using patient fixed effects:

$$H_{it} = \alpha_i + \beta_1 ARTdays_{it} + \varepsilon_{it}, \tag{5}$$

where H_{it} is a measure of patient i's health status (CD4 count or BMI) during the appointment at time t, α_i is a patient-specific fixed effect, and $ARTdays_{it}$ is the amount of time person i has been on ART as of April 1 of the year the interview took place (i.e. at approximately the time planting decisions were made for the relevant year). Since measures of health status are obtained during clinic visits, which do not necessarily coincide with the date of planting decisions, days on ART are used as a proxy measure of a patient's health status.

After establishing this relationship, our approach is to examine the reduced-form effect of ART on land fallowing decisions by estimating the following household-level fixed effects regressions:

$$F_{ht} = \alpha_h + \beta_1 ARTdays_{ht} + \beta_2 (ARTDays_{ht} \times QtyLand_h) + \sum_{\tau=2004}^{2006} \gamma_t YEAR_t^{\tau} + \varepsilon_{ht} \tag{6}$$

$$f_{ht} = \alpha_h + \beta_1 ARTdays_{ht} + \beta_2 (ARTDays_{ht} \times QtyLand_h) + \sum_{\tau=2004}^{2006} \gamma_t YEAR_t^{\tau} + \varepsilon_{ht} \tag{7}$$

where F_{ht} is the acres of land fallowed by household h at time t (years 2003–2006) and f_{ht} is the percent of household h's land fallowed at time t, α_h is a fixed effect for household h, $ARTdays_{ht}$ is defined as above, $QtyLand_h$ is the total cultivable acreage controlled by household h, and $YEAR_t$ are year effects where 2003 is the omitted baseline year. The variable $ARTdays_{ht}$ should be viewed as a proxy measure for health in household h at time t, and its effect on fallowing decisions at

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[12] Enrollment of adult patients during round 1 was not conditional on having already begun ART. Instead, we enrolled patients who were attending the AMPATH clinic. Then, using the AMPATH medical records system, we retrospectively determined which patients had begun receiving ART prior to the date of the round 3 interview. Some of these patients had initiated ART before round 1, whereas others had initiated ART between rounds 1 and 3, and still others had not yet initiated ART at the time of the round 3 interview (very few patients are in the latter group). The patients who had initiated ART at any point before the time of the round 3 interview are included in the sample.

[13] There are 17 households in our sample in which more than one household member received ART during the study period. In these cases we use the earliest ART start date for one of the HIV-infected adults in our analysis. We have also verified that if the sample is restricted to households with only one ART recipient, the results were unchanged.

time t is captured by the coefficient β_1 in Eq. (5). As such, a household's difference in this measure across survey rounds is interpreted as a measure of health improvements over this period. The interaction with $QtyLand_h$ variable is included in all specifications with acreage as a dependent variable in order to control for scale in households' fallow decisions. The coefficient γ_τ is included to control for annual trends in fallowing decisions for the entire community (ART and census sample households) that are not explained by time spent in AIDS treatment. While Eqs. (6) and (7) are primarily estimated by pooling the ART and census households, we also estimate the equations without the census sample in order to verify the trends in that sample are not driving the main results. This could be a concern if we expect fallowing trends in the census sample to differ significantly from those that would occur in the ART households in the absence of ART provision.

Our empirical strategy allows us to address a number of econometric concerns. By including household fixed effects in all of our estimations, we control for any heterogeneity in characteristics such as demographics, schooling, and family background, as well as unobservables such as ability and tastes, that are constant for households over time. The fixed effects specification also deals with the possibility that there is time-invariant variation across individuals in the accuracy of their self-reported data. Since fallowing decisions are also influenced by several time-varying factors, such as climate and macroeconomic conditions, we include data from the census sample of households to control for secular trends in the survey area; the year effect dummy variables control for such effects. Thus, our key identification assumption is that above and beyond the secular changes identified with data from the census sample, ART households do not differentially change their fallowing decisions between survey rounds due to factors other than the receipt of treatment, which is known to improve the health and extend the life of patients.[14] It is also important to emphasize that the timing of ART initiation among HIV-infected adults in our sample can be viewed as being exogenous. This is due to the fact that during the study period, individuals generally only sought HIV care after having progressed to rather advanced stages of the disease. This partly reflects a lack of awareness within the community about the less symptomatic stage of the disease as well as high levels of stigma. As stated earlier, most individuals initiating ART in our sample generally became infected 7–10 years before developing AIDS symptoms and seeking HIV care, at a time when knowledge of HIV was low. The overall implication of this is that random variation in the timing of infection – not individual characteristics – is likely to be the most important determinant of care-seeking behavior in our sample.

The empirical strategy described thus far will provide an estimate of the average effect of health improvements on fallowing decisions, but we are particularly interested in disentangling the productivity effect associated with a health shock from the discounting effect. As such, we also estimate household fixed effect regressions of the following form:

$$F_{ht} = \alpha_h + \beta_1 ARTdays_{ht} + \sum_{\tau=2004}^{2006} \gamma_\tau YEAR_t^\tau + \sum_n \beta_n (ARTdays_{ht} \times \theta_{nh}) + \varepsilon_{ht} \tag{8}$$

$$f_{ht} = \alpha_h + \beta_1 ARTdays_{ht} + \sum_{\tau=2004}^{2006} \gamma_\tau YEAR_t^\tau + \sum_n \beta_n (ARTdays_{ht} \times \theta_{nh}) + \varepsilon_{ht} \tag{9}$$

Variables are defined as in Eqs. (6) and (7), and θ_{nh} represents household characteristic n for household h. Household characteristics are chosen to characterize the labor endowment of the household to help isolate the discount rate effect as described in the Conceptual framework section; these include direct measures of household size as well as measures of household composition to describe productive labor capacity. We make use of household-level controls, such as wealth and various education measures, to isolate an independent effect of household size that is consistent with our household labor endowment hypothesis (and we continue to include households' total cultivable acreage in specifications with acreage as a dependent variable). It should be noted that results from estimating Eqs. (6)–(9) will reveal the reduced-form effect of ART provision and not necessarily the direct causal effect of health improvement. However, it is very likely that the health improvements due to ART are the main mechanism through which various other changes follow—such as those in transfers, labor supply, and other factors that might influence land fallowing decisions. The regressions estimated in the paper cannot separately identify the role of each these factors, but they are intended to instead measure the reduced-form effect of ART on fallowing decisions.

Since some individuals exit the sample between round 1 and round 3 due to death, relocation, or loss-to-follow up, selective attrition could give rise to biases in the estimated treatment effects. Due to the inevitable potential of mortality attrition, we interpret our estimates as the impacts of treatment on households whose patients were treated and survived (there is considerable evidence that patients who are very sick at the time of treatment initiation are less likely to survive even with ART). At the same time, we find no evidence that household composition changed significantly along observable characteristics, including the overall number of household members. This is true for both the ART sample and the census sample.[15] As reported in Table 2, about 15% of households that were in the ART sample in Round 1 were no longer in our

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[14] Of course, one limitation of this methodology is that it does not control for any time-variant characteristics that might be associated with both the duration on ART and with fallowing decisions. In this case, the coefficient of *ART days* will be biased. The inclusion of year fixed effects is meant to control for some of these time-variant characteristics. Moreover, in the Results section we also verify that our results are robust to the exclusion of census sample households.

[15] In regressions not reported in the paper, we use our rich dataset of observable characteristics to model the sample selection process in order to re-weight the sample using the inverse probability weights (IPW) technique (Fitzgerald et al., 1998; Wooldridge, 2002). None of our main results reported below are affected by these different estimation strategies. The IPW technique uses background and sexual behavior information from round 1 to predict the probability (p_i) that an individual i will still be observed in a future round. This person receives a weight equal to $1/p_i$, thus individuals whose observable characteristics predict higher attrition rates have more weight in the regression analysis.

sample in Round 3. Attrition in the census sample was 4.4% between rounds. Mortality and loss to follow-up is known to be high among patients initiating ART and as a result it is not surprising that there were higher attrition in the ART sample.

Results

Table 1 compares household characteristics of the census sample and the sample of HIV-infected households receiving ART. Most household characteristics are not significantly different between the two samples. On average, households in our sample have a little more than 6 members and are headed by a 48-year-old with approximately 7 years of formal education, and there is a significant amount of heterogeneity in these demographic features. Differences between ART and census households in acres of land owned are not statistically significant either. Households in the census sample maintain planting decisions over an average of 8.07 ac of land, compared to 6.80 ac for households in the ART sample. The average number of acres of land fallowed in round 1 is 4.81 and 3.71 in census and ART households, respectively. The amount of land fallowed equates to 44% of total landholdings in the census sample and 45% in the ART sample. The only notable characteristic in which households differ significantly is wealth, as proxied by radio ownership. The census sample households tend to own slightly more than 1 radio per household, while the ART sample tends to own slightly less than 1 per household.

Table 2 of the paper compares certain key characteristics in round 1 and round 3 of the survey, for the census sample and ART sample separately. There are no significant changes in the household size, average age of household members, and age of the household head.[16] On the basis of this and other comparisons, we can be confident that household composition does not change significantly over time. Table 2 also shows the duration of time that HIV-infected individuals in ART households were receiving ART in large and small households (defined as household size below or above the 75th percentile of household size). In round 1 (2004), the average number of days on ART was very small in both small and large households, whereas in round 3 (2006) the duration of time on ART had risen considerably. In round 3, however, ART duration is substantially shorter in large households, suggesting that ART patients in these households initiated ART later than they did in small households. Regression results in which the two households are compared, however, do adjust of ART duration. Fig. 1 shows that within ART households, there is variation in the duration of time on ART in each year and that the duration of time on ART increases over time. Very few households had an individual who was receiving ART in 2003; over time more households have a household member on ART and the average amount of time on ART increases.

In Table 3, we compare the characteristics of large and small households, as the comparison of these two types of households plays an important role in the regression analyses. We do observe differences in the comparisons between large and small households. Fallowing is significantly higher for households above the 75th percentile of household size, as they leave 5.8% more of their land fallow than households below the 75th percentile of household size. We also compared differences in fallowing patterns between households in which the patient is female or male, whether the household head is female or male, or whether the household head is single or married. We do not find significant differences in fallowing patterns in these comparisons (results not reported).

We begin our analysis by examining the relationship between ART and health. Fig. 2 plots the mean CD4 count in cells of twenty weeks before and after the initiation of treatment for our study population.[17] Fig. 3 shows a similar relationship for the BMI of patients. Both reveal a steady decline in health leading up to treatment and dramatic improvements in the period afterwards. Table 4 reports results from estimating Eq. (5) with CD4 count and BMI as the dependent variables. Here we see that time on treatment has a significant impact on health (columns 1 and 3). We also find that these health gains become smaller over time (columns 2 and 4), consistent with the clinical observation that patients recover much of their health within the first 6–12 months of treatment and typically maintain it thereafter.

Turning our attention to how natural resource management decisions are influenced by health improvements in the household, we employ the identification strategy described in Eqs. (6) and (7) to estimate the average impact of health improvements on the amount of land that a household leaves fallow. Table 5 presents our results for two different outcome measures of fallowing: acres of land fallowed and percent of total land owned that is fallowed. Columns 1 and 2 reveal the impact of treatment on the percentage of land fallowed, while columns 3 and 4 show the effect of ART on total acreage fallowed. In each case, the effect of ART is estimated with and without controls for the total amount of land owned by the household. In this table as well as in others that follow, the coefficient of the number of days on ART should be interpreted as the change in the outcome variable for an increase of 1 day in the duration of time on ART. Together these results suggest that the average overall effect of health improvements on fallow decisions is not statistically different from zero.[18],[19]

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[16] It should be noted, however, that any differences (or lack thereof) in time-varying characteristics between the ART and census samples are not informative of the validity of our overall design since one would expect households that have experienced a health shock to be different in wealth, fallowing behavior, and other time-varying characteristics.

[17] Due to the low frequency at which CD4 count is measured, we chose a group size that is large enough to produce a relatively smooth curve. When mean CD4 counts are calculated for intervals of less than 10 weeks, the figure looks similar. Likewise, a similar pattern is evident when mean CD4 count is calculated in each time interval.

[18] Since ART households have 6.8 ac on average, the effect of ART on fallowing, as one would expect, is nearly identical in the two specifications.

[19] We also estimated additional regressions to determine whether the number of distinct plots a household owned modified the effect of ART. We did this by including an interaction term between ART and the number of plots of land owned by a household. The interaction term was not statistically significant. We also note that land sales and acquisitions over the 3 year period of our study are extremely low. Only 4% of households in the sample sold land between 2004 and 2006; and 5.5% of households purchased land; changes in quantity of land owned did not affect the results.

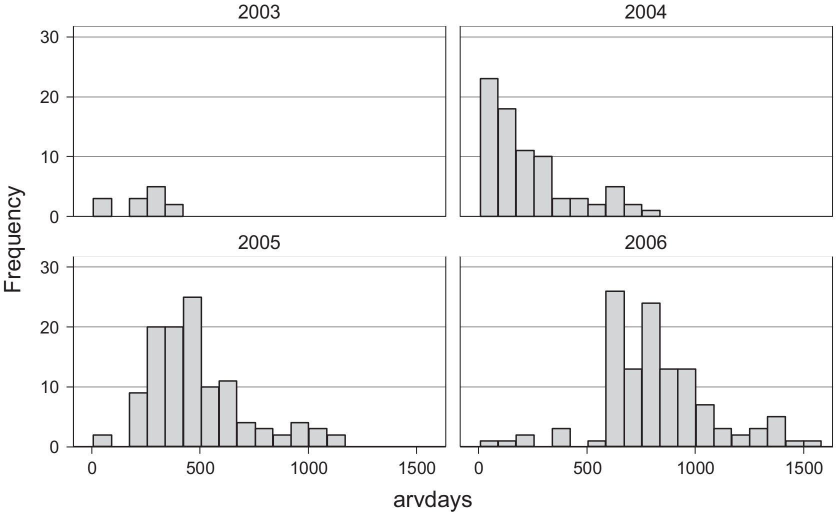

Fig. 1. Distribution of duration of time on ART in each study year.

Table 3
Comparisons between Large (over 75th percentile) and smaller households.

	Household size: below 75th percentile		Household size: above 75th percentile		*P*-value[*]
	Mean	Std. dev.	Mean	Std. dev.	
Number of households	388		168		
Demographics					
Average age of household members	26.11	12.62	21.69	5.35	0.00
Age of household head	46.93	15.87	52.64	11.84	0.00
Wealth					
Radios owned by household	0.96	0.73	1.23	0.91	0.00
Education of Household head					
Years of schooling	7.12	4.01	6.34	3.95	0.03
Completed primary school	0.46	0.50	0.36	0.48	0.02
Completed secondary school	0.24	0.43	0.20	0.40	0.21
Land holdings					
Total acres of land (Round 1)	7.04	10.01	9.52	11.01	0.01
Fraction of land fallowed (Round 1)	0.42	0.31	0.48	0.27	0.03

[*] *P*-values provided for two-tailed *t*-tests; equal variances between the two samples are not assumed.

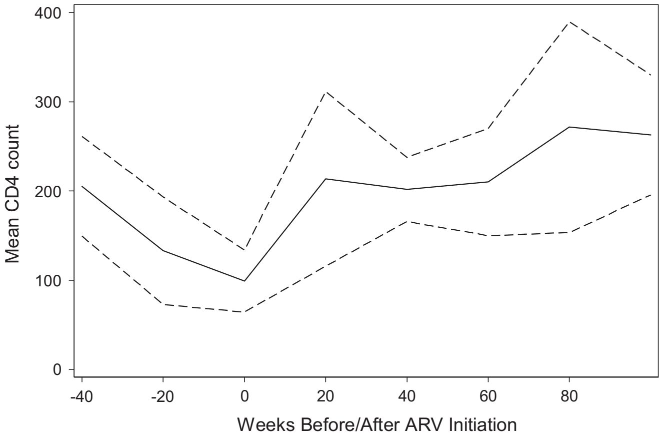

Fig. 2. CD4 count before and after initiation of ART.

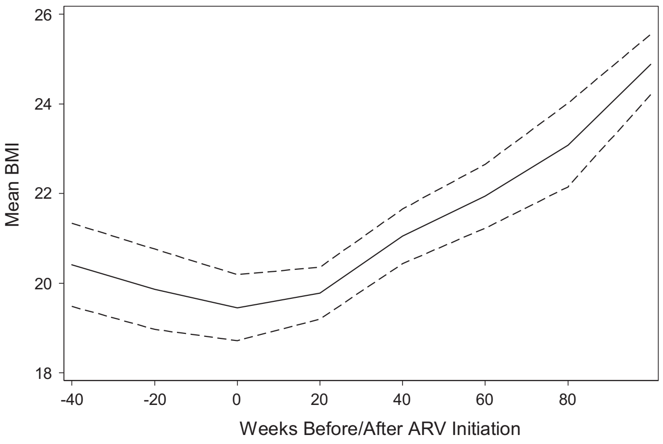

Fig. 3. Body mass index before and after initiation of ART.

Table 4
Impact of ART on health, with individual fixed effects.

	CD4 T-cell count		BMI	
	(1)	(2)	(3)	(4)
Days on ART	0.317***	0.512***	0.00313***	0.00786***
	(7.239)	(4.920)	(3.710)	(3.535)
Days on ART squared		−0.000257**		−0.000006**
		(−2.056)		(−2.279)
Observations	116	116	668	668
Number of individuals	44	44	36	36
R-squared	0.42	0.46	0.17	0.24

Absolute value of t statistics in parentheses. Regressions include individual (patient) fixed effects.
** Significant at 5%.
*** Significant at 1%.

Table 5
Impact of ART on fallow land (percent and acres of land).

Dependent variable:	(1)	(2)	(3)	(4)
	Percent fallow		Acres fallow	
Days on ART	−0.00240	−0.00297	0.000192	−5.38e−05
	(0.00336)	(0.00382)	(0.000772)	(0.000863)
Days on ART qty. of land		7.18e−05		3.11e−05
		(0.000398)		(0.000185)
Mean (dependent var.):	50.90	50.90	5.07	5.07
R-squared	0.063	0.063	0.009	0.009
Number of hhn	624	624	624	624

Standard errors in parentheses. Regressions include household fixed and year effects.

The absence of a clear average treatment effect is consistent with our ambiguous theoretical predictions and suggests the need for a more disaggregated approach to disentangle the competing effects of health on labor productivity and discount rates.

Our first approach to separately identify these effects uses several measures of a household's labor endowment to estimate Eqs. (8) and (9). We use percent of land fallowed as the outcome variable (Eq. (9)), but the nature of the results are similar when number of acres of land fallowed is the outcome variable (Eq. (8)). We focus on labor endowments with the supposition that larger households may be better equipped to reallocate labor to agricultural activities, thus minimizing the importance of the productivity effect on overall acreage fallowed and potentially allowing us to identify the competing discount rate effect.[20] Table 6 presents results using specifications with various combinations of household size, household size squared, and the age structure of the household. Since the productivity effect is likely to be least pronounced in the largest of households, we also include a dummy variable indicating whether a household has more than seven members living at home, which corresponds to a household size at approximately the 75th percentile.

The second column of Table 6 shows that the effect of health improvements on fallowed acres are decreasing in household size, but increasing in the square of household size. When we turn our attention to families at or above the 75th percentile in terms of household size (column 3 of Table 6), we see that health improvements lead to substantial increases in the percent of acreage fallowed by these larger households. While smaller households have a 0.54 percentage point decrease in the percent of land that is fallowed at 100 days on treatment, these larger households have a 0.45 percentage point increase in the percent of land that is fallowed after 100 days of ART.[21] Column 5 shows that households with, on average, younger members increase their percentage of fallowed land more as they get healthier, relative to households with older members. In addition, Column 6 indicates that households with more children under the age of six have a greater increase in their land fallowing as they get healthier, relative to households with less young children (this final result is significant only at the 10% level.) Since younger families (controlling for small children) are likely to have more productive labor available, this is further evidence of labor substitution in the face of a health shock and suggests that younger families are less likely to have fallowed acres impacted by a binding productivity effect. Together with the effect of household size, these results provide strong support for our contention that a large labor endowment minimizes the productivity impacts from a health shock, leaving the discount rate effect to dominate, and thus leading to greater levels of environmental conservation in response to health improvements.

Table 7 presents results based on the same regression models as those in columns 1 and 3 of Table 6 but on subgroups of households that had individuals who were very sick ($CD4 < 50$) and not very sick ($CD4 \geq 50$) at the time of ART initiation. The results suggest that households with individuals who were very sick at the time of ART initiation were less likely to fallow land as ART duration increased, whereas households with an individual above the median CD4 count were more likely to fallow land as ART duration increased. This finding is consistent with the notion that the productivity effect dominates the planning horizon effect for households which experienced the largest health gains ($CD4 < 50$ at the time of ART initiation). We cannot, however, rule out the possibility that the progression of AIDS is correlated with other health shocks in the household, and thus that the pattern of results is also consistent with a mean reversion effect as those other members recover from their illness.[22] Due to the small sample sizes and exploratory nature of this analysis, further research will be needed to arbitrate between the two explanations.

One concern about these results is that the census sample may not be very relevant for identifying time trends in fallowing in the absence of ART. This is one of the assumptions of the empirical strategy, but to verify that the results do not hinge on the inclusion of the census sample, we estimate Eq. (7) with only the sample of ART households. In this case, the time trends will be identified by annual variation in fallowing patterns among all ART households, and the effect of ART will be identified by changes in fallowing that are associated with ART duration (after controlling for annual trends). The results from estimating Eq. (9) with only the ART sample are reported in Table 8. Although the sample of ART households is relatively small, the main result still remains the same: large households increase the percent of land fallowed as ART duration increases.

Another concern is that our measures of labor endowments may be capturing the influence of other household characteristics that might be correlated with household size. Since non-agricultural asset wealth can be liquidated to help cope with health shocks, and household size and wealth may be correlated, we confirm that the effect of household size is robust to the inclusion of controls for asset wealth. Table 9 presents results when we include a measure of household wealth and an indicator variable for whether the household head completed secondary school. Column 1 suggests that wealthier families conserve more as they become healthier relative to poorer families, but the results in column 2 show that the wealth effect is not significant when we control for the effect of household size. In fact, the significant difference between large and small household persists even after controlling for wealth. Column 3 indicates a similarly positive influence of education—that households whose head completed secondary school conserve more as they become healthier, and this result remains significant when the household size variable is included (column 4). Here again we see that the effect of household size persists, and the same is true in column 5 where controls for education, average age, and number of young

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[20] More than half of all households hired labor to work on their farms in 2006, but this did not statistically differ between ART and non-ART households (Chi2 test $p=0.96$). Unsurprisingly, smaller households are more likely to hire labor (58%) than large households (46%) (Chi2 test $p=0.007$). We used a household fixed effects regression to examine how the use of hired labor was associated with the number of days on ART and household size >7. We find that there was no effect of ART on whether or not households used hired labor, and this did not differ between large and small households either. In addition, households do report receiving transfers from other households and there is some evidence that the amount of transfers received declines as the duration of time on ART increases. This suggests that households do have other coping mechanisms in response to health shocks, but it does not take away from the fact that land use appears to be one of the mechanisms as well.

[21] These results are robust to the use of alternative household size categories. The choice of a cutoff of 6 members (roughly the 55th percentile of household size) led to qualitatively identical but slightly smaller point estimates, with significance at the 5% level. The choice of an 8 member cutoff (roughly the 80th percentile of household size) led to extremely similar point estimates, but two results were only significant at the 10% level. This is likely due to the reduced number of observations at this higher threshold for classifying households as large.

[22] It is important to note that mean reversion due to HIV disease does not threaten our causal interpretation here, as nearly all AIDS-infected persons who do not receive ART experience dramatic declines in their CD4 counts followed by premature death.

Table 6
Impact of ART on fallow land: labor endowment effects.

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)
	Percent of land that is fallow					
Days on ART	−0.00240	0.00270	−0.00541*	−0.00332	0.00745	0.0112*
	(0.00336)	(0.00823)	(0.00379)	(0.00432)	(0.00690)	(0.00745)
Days on ART * HH size		−0.00433				
		(0.00284)				
Days on ART * (HH size)^2		0.000516**				
		(0.000258)				
Days on ART * HH size>7			0.01000**	0.0121**	0.0116**	0.0145***
			(0.00435)	(0.00499)	(0.00448)	(0.00527)
Days on ART * # children ≤ 5				−0.00499		−0.00653
				(0.00562)		(0.00573)
Days on ART * avg. age					−0.000459*	−0.000497**
					(0.000245)	(0.000248)
Mean (dependent var.):	50.90	50.90	50.90	50.90	50.90	50.90
R-squared	0.063	0.069	0.067	0.068	0.072	0.074
Number of hhn	624	624	624	624	624	624

Standard errors in parentheses. Regressions include household and year fixed effects.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 7
Impact of ART on fallow land based on initial health status.

Variables	(1)	(2)	(3)	(4)
	Percent of land that is fallow			
	CD4 < 50	CD4 ≥ 50	CD4 < 50	CD4 ≥ 50
Days on ART	−0.0677	0.185	−0.0748	0.198
	(0.0694)	(0.130)	(0.0675)	(0.122)
Days on ART * HH size>7			0.0159**	0.0231
			(0.00580)	(0.0183)
Observations	26	42	26	42
R-squared	0.483	0.275	0.516	0.346
Number of hhn	9	11	9	11

Standard errors in parentheses. Regressions include household and year fixed effects. CD4 represents the CD4+ T-cell count of individuals at the time of ART initiation.
** Significant at 5%.

Table 8
Impact of ART on fallow land: labor endowment effects, without census sample.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Percent of land that is fallow					
Days on ART	0.00958	0.0146	0.0144	0.0141	0.0155	0.0151
	(0.0122)	(0.0121)	(0.0124)	(0.0124)	(0.0124)	(0.0124)
Days on ART * HH size		0.00671				
		(0.00617)				
Days on ART * (HH size)^2		−0.000263				
		(0.000449)				
Days on ART * HH size>7			0.0145***	0.0148***	0.0141**	0.0150***
			(0.00537)	(0.00560)	(0.00540)	(0.00558)
Days on ART * # children ≤ 5				−0.00110		−0.00390
				(0.00581)		(0.00585)
Days on ART * avg. age					−0.000230	−0.000318
					(0.000287)	(0.000293)
Mean (dependent var.):	49.61	49.61	49.61	49.61	49.61	49.61
R-squared	0.027	0.072	0.055	0.055	0.058	0.060
Number of hhn	137	137	137	137	137	137

Standard errors in parentheses. Regressions include household and year fixed effects.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 9
Impact of ART on fallow land: Robustness to inclusion of other characteristics.

VARIABLES	(1)	(2)	(3)	(4)	(5)
	Percent of land that is fallow				
Days on ART	−0.00761 (0.00482)	−0.00871* (0.00498)	−0.0105*** (0.00377)	−0.0114** (0.00483)	0.00557 (0.00712)
Days on ART * HH size>7		0.00850** (0.00402)	0.00945** (0.00429)	0.00901** (0.00421)	0.0151*** (0.00513)
Days on ART * education			0.0160*** (0.00612)	0.0155** (0.00620)	0.0173*** (0.00614)
Days on ART * avg. age					−0.000441* (0.000246)
Days on ART * # children ≤ 5					−0.00990* (0.00584)
Days on ART * wealth	0.00506 (0.00407)	0.00370 (0.00400)		0.00125 (0.00386)	
Mean (dependent var.):	50.90	50.90	50.90	50.90	50.90
R-squared	0.064	0.066	0.076	0.075	0.084
Number of hhn	621	621	620	618	620

Standard errors in parentheses. Regressions include household and year fixed effects.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

children are all included. The significant coefficient on household size is stable through all specifications, providing evidence that the household labor endowment influences resource management decisions in a manner consistent with our theory.[23]

Finally, we re-run our preferred specifications using only 2003 and 2006 data to confirm that the longer recall periods associated with the fallow data from 2004 to 2005 were not biasing our results. As revealed in Table 10, our primary results are robust to this alternative approach.

Taken together, our results provide strong evidence that the way in which fallowing decisions depend on improvements in health depends strongly on the total size of the household. As larger households become healthier, they leave more land fallow—a result that does not hold for smaller households. Given that land fallowing is the primary means of investment in soil quality among households in our study region and that agriculture is labor-intensive, a result that larger households increase their fallowing as health improves provides strong evidence that treatment lowers households' discount rates. Indeed, a back-of-the envelope calculation based on column 3 in Table 6 suggests that the discount rate of large households increases by slightly more than 1.5 percentage points after one year of ART.[24]

The main results in the paper can also be viewed more easily in Fig. 4, which shows the effects of estimating a fixed-effects regression in which ART duration is represented by six month indicators. These binary indicators of ART duration are interacted with households size being above the 75th percentile, so that the trends for the two types of ART households can be seen easily. The figure includes 95% confidence intervals for the point estimates. Although the small sample of households restricts our ability to detect significant differences between large and small households at every 6 month interval, the differences between the two groups are generally significant in most time periods. More importantly, Fig. 3 shows that the difference between large and small households in the percent of land fallowed grows by the largest amount immediately after ART is initiated and remains similar thereafter.

Conclusion

In this paper, we developed a conceptual framework for assessing the effect of health shocks on natural resource management in subsistence households in low-income settings. The impact of health shocks operates through two distinct and competing channels by influencing labor productivity and discount rates. Sicker households are less able to extract

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[23] The results in Table 9 are also robust to excluding the census sample from the analysis.

[24] Note that we focus on the change in discount rates for large households since the effect of changing labor endowments on fallowing decisions is minimal for those households that have many members. Adding the two coefficients in Column 3 of Table 6 together suggest that each day on ART increases fallow by.0046 percentage points. Thus, one year on treatment will increase fallow by 1.68 percentage points. If household land quality is heterogeneous such that the return to fallow will vary across plots, we know that the return to fallow of the marginal plot must equal the discount rate. If we assume the distribution of land quality is uniform, the change in discount rate is equal to the change in fallow rates, or 1.68 percentage points. If the quality of land is distributed normally, that change will be slightly larger since baseline fallow rates for this sample are 48% and thus suggest a discount rate close to the mean return to fallow.

Table 10
Impact of ART on fallow land: 2003 and 2006 data only.

Variables	(1)	(2)	(3)	(4)
	Percent of land that is fallow			
Days on ART	−0.00335 (0.00472)	−0.0138** (0.00550)	0.000609 (0.00970)	−0.0132* (0.00700)
Days on ART * education		0.0180** (0.00699)	0.0183*** (0.00697)	
Days on ART * HH size>7		0.0115** (0.00507)	0.0153*** (0.00569)	
Days on ART * avg. age			−0.000361 (0.000268)	
Days on ART * # children ≤5			−0.00734 (0.00627)	
Days on ART * wealth				0.00853* (0.00452)
Mean (dependent var.):	48.72	48.72	48.72	48.72
R-squared	0.078	0.102	0.107	0.086
Number of hhn	622	618	618	619

Standard errors in parentheses. Regressions include household and year fixed effects.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

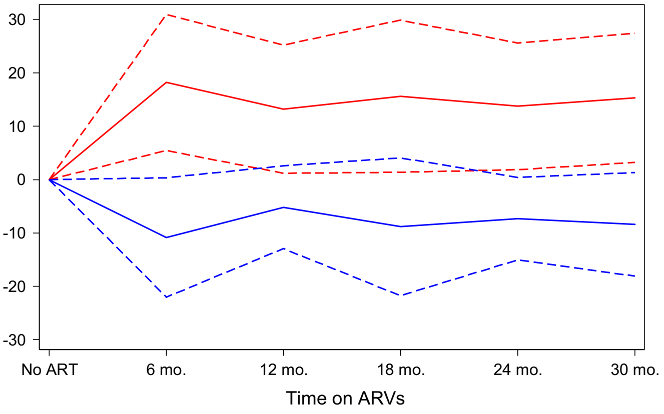

Fig. 4. Estimated change in percent of land fallowed vs. duration of ART (in months). *Notes*: Figure shows estimated coefficients from household fixed effects regression of percent land fallowed on 6 month indicators of ART duration as well as interactions between large household size (≥ 7 household members) and the 6 month indicators.

natural resources, but also have a diminished incentive to conserve them. Thus, the net impact of health shocks is ambiguous. Which effect dominates is shown to depend, in part, on household size since larger households, which are better equipped to reallocate labor in response to the illness of a household member, are less susceptible to the influence of health on household productivity.

We examine this problem empirically by studying the relationship between health improvements associated with AIDS treatment and household land fallowing decisions. The average effect of treatment on land fallowing is zero. An examination based on household characteristics, however, reveals more interesting and heterogeneous impacts. In particular, large households fallow more land as they become healthier and these impacts are robust to a wide range of specifications. These results are consistent with predictions from our conceptual framework and together provide strong evidence for both productivity and discount rate effects in response to health changes. At the same time, our paper does not specify the exact changes in discount rates and productivity that can explain the changes in land fallowing we observed. An important area for future research is the estimation of agricultural production functions and more structural models that can quantify the changes in discount rates and labor productivity needed to explain our results.

These findings have important policy implications. The United Nations Millennium Development Goals include health, wealth, and environmental targets, which some have argued may be in conflict with one another. Health improvements in small households will greatly improve household consumption, but perhaps at the expense of the environment. In contrast, large households may conserve more in response to health improvements, but consumption impacts may be small. As such, a differentiated approach may be required to ensure that all goals are met in the most efficient manner possible.

Appendix

In this appendix we detail the derivation from Eqs. (3) and (4) in the main body of the paper. Recall that farmer's maximization problem defined in the Conceptual framework section implies the following relationship between health shocks and resource conservation:

$$\frac{dk}{d\Phi} = -\frac{\frac{\partial^2 U}{\partial L \partial X}\alpha(hl)^{\alpha-1}k^{1-\alpha}\frac{\partial h}{\partial \Phi}l\frac{1-\alpha}{\alpha}\frac{l}{k} - \frac{\partial \delta}{\partial \Phi}}{\frac{\partial^2 U}{\partial L \partial X}(hl)^{\alpha}(1-\alpha)k^{-\alpha}\frac{1-\alpha}{\alpha}\frac{l}{k} - \frac{\partial U}{\partial L}\frac{1-\alpha}{\alpha}\frac{l}{k^2}} \tag{A1}$$

The concavity assumptions ensure that the sign of the denominator is negative, so the influence of health on natural capital extraction rates, and conversely on resource conservation, will depend on the sign of the numerator. A negative denominator also implies the following:

$$\frac{\frac{\partial^2 U}{\partial L \partial X} \le \left(\frac{\partial U}{\partial L}\frac{1-\alpha}{\alpha}\frac{l}{k^2}\right)}{\left((hl)^{\alpha}(1-\alpha)k^{-\alpha}\frac{1-\alpha}{\alpha}\frac{l}{k}\right)} = \frac{\left(\frac{\partial U}{\partial L}k^{\alpha-1}\right)}{\left((hl)^{\alpha}(1-\alpha)\right)} \tag{A2}$$

Plugging in the right-hand-side of (A2) into the numerator of (A1) provides a sufficient condition for the (A1) to be positive and thus for health shocks to increase resource conservation. This condition is as follows:

$$\frac{\left(\frac{\partial U}{\partial L}k^{\alpha-1}\right)}{\left((hl)^{\alpha}(1-\alpha)\right)\alpha(hl)^{\alpha-1}k^{1-\alpha}\frac{\partial h}{\partial \Phi}l\frac{1-\alpha}{\alpha}\frac{l}{k} \ge \frac{\partial \delta}{\partial \Phi}} \tag{A3}$$

Algebraic manipulation and assuming equality, in turn, yields the following expression:

$$\frac{\partial U}{\partial L}\frac{\partial h}{\partial \Phi}\frac{l}{k} = h\frac{\partial \delta}{\partial \Phi} \tag{A4}$$

Finally, combining our first-order conditions to solve for $\partial U/\partial L$ and substitution yields the following:

$$\frac{\partial h}{\partial \Phi}\frac{\Phi}{h}\alpha = \frac{\partial \delta}{\partial \Phi}\frac{\Phi}{\delta}(1-\alpha) \tag{A4}$$

Recognizing that the first term on the left-hand-side of (A4) is the elasticity of effective labor with respect to health and that the first term on the right-hand-side of (A4) is the elasticity of the discount function with respect to health, we obtain the following:

$$\alpha\eta_h = (1-\alpha)\eta_\delta \tag{A5}$$

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