HIV/AIDS and Rural Livelihoods in Zambia: A Test of the New Variant Famine Hypothesis

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ABSTRACT
The 'new variant famine' (NVF) hypothesis postulates that the HIV/AIDS pandemic is eroding rural livelihoods and making rural households more vulnerable to drought and other transitory shocks. Despite limited empirical evidence, the NVF hypothesis has become an important part of the conventional wisdom surrounding the relationship between HIV/AIDS and food crises in southern Africa. This study provides a new empirical test of the NVF hypothesis via econometric estimation of the relationship between AIDS-related morbidity and mortality and indicators of rural livelihoods. District longitudinal data from smallholder farmers in Zambia surveyed annually between 1991 and 2003 are used to estimate several econometric models in order to: (1) understand the effects of HIV/AIDS on rural farm production; (2) measure whether HIV/AIDS exacerbates the impacts of drought and other factors affecting rural farm production; and (3) determine whether these results are consistent with the predictions of the NVF hypothesis. We find little evidence of a systematic decline in rural livelihoods at the national or provincial level as measured by mean household agricultural production, area cultivated, or the value of production per unit of land. Furthermore, contrary to *a priori* expectations, we do not find evidence of a robust negative *direct* effect of HIV/AIDS on any of these three agricultural production outcomes. We do find some evidence that HIV/AIDS may have negative *indirect* effects on rural farm production by exacerbating the impacts of drought, gender inequalities and agricultural sector policy changes related to structural adjustment. This final finding is consistent with the predictions of the NVF hypothesis.

1. INTRODUCTION

The 'new variant famine' (NVF) hypothesis has become an important part of the conventional wisdom surrounding the relationship between HIV/AIDS and food crises in southern Africa. The NVF hypothesis has begun to shape HIV/AIDS mitigation and food security policies and programs of governments and development agencies (de Waal and Tumushabe, 2003). The NVF hypothesis suggests, *inter alia*, that HIV/AIDS is causing a decline in rural livelihoods and that the epidemic is making rural households more sensitive and less resilient to drought and other transitory shocks (de Waal and Whiteside, 2003; de Waal, 2004). Although a growing body of literature suggests a decline in agricultural productivity and productive assets among HIV/AIDS-afflicted households compared to non-afflicted households[5] (reviewed in Gillespie and Kadiyala, 2005; and Barnett and Whiteside, 2002), there remains a dearth of empirical evidence to support the specifics of the NVF hypothesis (de Waal, 2004). Furthermore, to date, no studies have been specifically designed to test the predictions of the NVF hypothesis (de Waal, 2007).

This study represents a first step towards testing the predictions of NVF. We estimate the impact of AIDS-related morbidity and mortality on indicators of rural livelihoods in Zambia. Most people affected by HIV/AIDS rely on agriculture for their livelihoods (Gillespie, 2006); hence we focus specifically on the impact of HIV/AIDS on household agricultural production, area cultivated, and the value of production per unit of land (henceforth referred to as 'agricultural production outcomes' or 'rural farm production'). The study is based on econometric analysis of district-level panel data derived from nationally representative household surveys from 1991 to 2003. The analysis is designed to: (1) understand the potential lagged

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[5] This paper follows the taxonomy convention of Barnett and Whiteside (2002): "Afflicted" households are those that have incurred a prime-age death in their households and those households in which a member is currently HIV positive. Households that have not directly suffered a death and do not have a member living with HIV/AIDS but are nevertheless affected by the impacts of death in the broader community are referred to in this study as "affected." Households not directly suffering an HIV/AIDS-related death or illness may be non-afflicted, but it is doubtful that there are many non-affected households in hard-hit communities of eastern and southern Africa.

effects of AIDS morbidity and mortality on current and future agricultural production outcomes; (2) measure the extent to which HIV/AIDS may exacerbate the impacts of other factors affecting rural farm production, such as macroeconomic structural adjustment, drought, and agricultural sector policy changes; and (3) determine whether these trends and impacts are consistent with the predictions of the NVF hypothesis. The study aims to strengthen the empirical foundation of food security policies and programs responding to the HIV/AIDS crisis in southern Africa.

Apart from the availability of national longitudinal district data, Zambia is a suitable test case of the NVF hypothesis because rural farm households in the country are experiencing the ravages of HIV/AIDS as well as recurrent droughts. In 2006, UNAIDS estimated that the HIV prevalence rate among adults (aged 15-49) was 17%, placing Zambia among the six most-highly afflicted countries in the world (UNAIDS, 2006). Drought has also plagued the country, with five droughts occurring between 1991 and 2003 (Govereh and Wamulume, 2006; Del Ninno and Marini, 2005). In addition to being faced with recurrent drought and HIV/AIDS, smallholder[6] farmers in Zambia have had to adapt to structural adjustment reforms implemented in the 1990s. These reforms included large reductions in government fertilizer subsidies, the withdrawal of marketing boards infrastructure, and the elimination of pan-territorial pricing for maize, the main staple food crop in the country (World Bank, 2004). Understanding the impact of HIV/AIDS on rural farm production requires controlling for these other exogenous shocks facing the agricultural sector, as well as accounting for potential interaction effects between these processes.

The remainder of this paper is organized as follows: Section 2 describes the predictions of the new variant famine hypothesis and reviews the evidence to date in support of NVF. Section 3 presents the methods and data used in the study. Section 4 describes the results and Section 5 outlines the conclusions and policy implications of the study.

2. BACKGROUND ON THE NEW VARIANT FAMINE HYPOTHESIS

2.1. The 'new variant famine' hypothesis and its predictions

The background discussed below is drawn from papers by de Waal and Whiteside, 2003, de Waal and Tumushabe, 2003, and de Waal, 2003. The NVF framework predicts two main trends over time due to the HIV/AIDS epidemic in southern Africa: (1) declining rural livelihoods; and (2) increasing sensitivity and decreasing resilience of rural communities to drought and other external shocks. The rationale for the first trend is that the burden of care giving, lost labor, money, and lost social and emotional support are all eroding rural livelihoods. The burden of care is expensive in terms of time (e.g., caring for the sick and orphans, attending funerals) and money (e.g., paying for medical and funeral expenses) for both afflicted and non-afflicted households. Furthermore, HIV/AIDS-related mortality among prime-age adults, particularly women, reduces the number of productive adults that provide for dependents while also increasing the number of dependents. This results in high effective dependency ratios[7] and potential labor shortages.

The rationale for the second trend predicted by the NVF hypothesis is that longstanding coping strategies used by households to mitigate the impacts of drought and other shocks may no longer be effective since the onset of AIDS. For example, even in the absence of other shocks, households may sell assets to pay for AIDS-related medical or funeral expenses. Such asset depletion may undermine the household's ability to cope with drought-related shortfalls in crop production. In addition, AIDS-related morbidity and mortality can disrupt the intergenerational transfer of knowledge related to famine coping strategies (e.g., gathering wild foods or income generating activities) on which households rely to reduce the impacts of drought and other shocks. According to de Waal and Whiteside (2003), a common coping strategy historically in times of drought was for adults to reduce their food consumption; however, in the era of HIV/AIDS, such a strategy is dangerous because poor nutrition accelerates the progression from HIV to AIDS and also increases the susceptibility of non-afflicted individuals to HIV infection. Kinship networks are also being stressed by AIDS-related illness and deaths and so social networks may be less able to absorb the impacts

[6] By 'smallholder' we mean households that cultivate fewer than 20 hectares of land.
[7] The effective dependency ratio is defined as the number of dependents (children, the elderly, and the ill) divided by the number of productive adults (de Waal and Whiteside, 2003).

of other shocks. Finally, de Waal suggests that the burden of care described above forces households to adopt less productive and less resilient farming practices.

2.2. Evidence for the new variant famine hypothesis

The two broad predictions of the NVF hypothesis described above grow out of three NVF 'sub-hypotheses': that HIV/AIDS leads to (1) "new patterns of vulnerability to destitution and hunger"; (2) "new trajectories of destitution during crisis"; and (3) changes in the "ecology of nutrition and infection, and thereby the pattern and level of child mortality" (de Waal, 2007). In his chapter on NVF in the 2007 book, *The New Famines* (Devereux, 2007), de Waal outlines the evidence to date in support of each of these NVF sub-hypotheses. The majority of this evidence is either indirect or circumstantial; in fact, de Waal acknowledges that no studies have been designed specifically to test the predictions of NVF (de Waal, 2007) – our paper is the first to do so. Few of the papers cited as evidence of NVF control for other factors affecting rural livelihoods nor do they attempt to empirically test the hypothesis that HIV/AIDS is exacerbating the effects of other shocks on rural livelihoods. Furthermore, most of the works cited as evidence are from limited geographic areas or are based on a 'snapshot' of the epidemic's impact rather than trends over a number of years. Given the 'long-wave' nature of HIV/AIDS, it is important to consider the immediate *and* delayed impacts of the epidemic (Gillespie, 2006; Barnett and Whiteside, 2002). Moreover, case studies based on localities known to be hard-hit by the disease may generate conclusions that do not accurately reflect broader national-level impacts.

In terms of evidence for the NVF sub-hypothesis that HIV/AIDS is creating "new patterns of vulnerability to destitution and hunger" (de Waal, 2007), de Waal points to several small-scale studies (Barnett and Blaikie, 1992; Webb and Mutangadura, 1999; and Baylies, 2002) that have explored the impacts of HIV/AIDS on household and community food security in rural Africa. While these studies provide valuable insights into the social and economic impacts of HIV/AIDS on rural households, all three of the studies focus on relatively limited geographic areas, often with high HIV prevalence rates, and so are not nationally representative or easily generalized. The work by Barnett and Blaikie (1992) and Baylies (2002) is largely qualitative and so does not permit measurement of the relative magnitude of the HIV/AIDS impact on households relative to other shocks and factors affecting rural livelihoods. The work by Webb and Mutangadura (1999) has a quantitative component and includes comparisons between affected and unaffected households with respect to various socio-economics indicators; however, it is not clear if differences in income and other indicators are statistically significant or if there are other differences between the affected and unaffected households that could be responsible for the income differential. Nonetheless, these and a plethora of other household-level studies (see Gillespie and Kadiyala, 2005 for a thorough review) suggest that HIV/AIDS is negatively impacting afflicted households' incomes, asset levels, and agricultural production.

None of the aforementioned papers allows comparison of the impact of drought on HIV-affected households and communities versus those less affected by the epidemic. However, a pilot study in Tanzania which examined the impacts of the 2002/3 drought on households experiencing adult morbidity and mortality versus non-afflicted households found, contrary to the predictions of NVF, that afflicted households were actually better off than non-afflicted households in the face of drought (Tumushabe, 2005). One reason cited for this counter-intuitive finding is that the households affected by adult chronic illness and death also tended to be better off, underscoring the importance of controlling for other factors in order to isolate the impact of HIV/AIDS on rural livelihoods (Jayne et al. 2005).[8]

[8] A major difficulty in measuring the impact of mortality attributable to AIDS is that it is caused by behavioral choices rather than by random events. Individuals and households incurring adult mortality are more likely to display certain characteristics. Especially in the early years of the epidemic in sub-Saharan Africa, evidence suggests that men and women with higher education and income were more likely to contract HIV because they tended to have more sexual partners (Ainsworth and Semali, 1998; Gregson, Waddell, and Chandiwana, 2001). More recently, there is some evidence to suggest that poverty is increasingly associated with HIV infection, especially among women. Regardless, a failure to control for initial household characteristics may generate biased estimates of the impacts of AIDS.

While HIV/AIDS has undoubtedly had a devastating impact on many of the households it has touched, de Waal cites several papers that call attention to the effectiveness of household coping strategies in many instances. One such coping strategy is so-called "replacement" in which households experiencing a prime-age death attract new household members, thereby mitigating the labor force impact of the death (Yamano and Jayne, 2004; Mather et al., 2003). de Waal suggests that households that use the replacement coping strategy might be more vulnerable to subsequent shocks; however, to date, no studies have empirically tested this hypothesis (de Waal, 2007).

A weakness in much of the evidence presented by de Waal is that it consists of facts and figures on how HIV/AIDS is impacting afflicted households but gives little ground for comparison with non-afflicted households, nor does it directly support the claim that HIV/AIDS exacerbates the effects of drought and other shocks on rural livelihoods. For example, de Waal cites a study from rural South Africa (Steinberg et al., 2002) that indicates that half of the AIDS-afflicted households in the sample "reported that their children were going hungry as a result" (de Waal, 2007: 93). But to what extent were children going hungry in the non-afflicted households in the study area? Were there factors other than HIV/AIDS that were contributing to the child malnutrition problem?

In several other papers on the NVF hypothesis, de Waal lists among the evidence for NVF increased cassava cultivation in several southern African countries (de Waal and Whiteside, 2003; de Waal, 2004). While this upward trend is striking, other factors such as agricultural policy changes, including dismantling of marketing boards infrastructure and reductions in maize and fertilizer subsidies are likely to be as, if not more, important than HIV/AIDS in influencing this shift (Jayne et al., 2005; Chapoto, 2006).

While the evidence presented by de Waal in support of the NVF sub-hypothesis of "new patterns of vulnerability to destitution and hunger" shows that HIV/AIDS often has a negative effect at the household level, none of the evidence directly supports the claim that affected households are harder hit by drought and other shocks. While it is certainly plausible that such households are more vulnerable to shocks, as their ability to cope is worn down by the impacts of the epidemic, to date no explicit empirical evidence supports this claim.

In terms of the NVF sub-hypothesis that affected households and communities will follow "new trajectories of destitution during crisis", de Waal states that "this prediction has yet to be tested" (de Waal, 2007: 95). The two main sources of circumstantial evidence for this NVF sub-hypothesis are a report by the Southern African Development Community Food and Natural Resource Vulnerability Assessment Committee (SADC, 2003) and a paper on AIDS, child malnutrition, and drought in southern Africa by John Mason and colleagues (Mason et al., 2005). Similar weaknesses to those outlined above recur for this evidence for the NVF hypothesis. de Waal points to a finding in the SADC report that 57% of households with a chronically ill adult (used as a proxy for AIDS-afflicted households) had not eaten for entire days (de Waal, 2007: 95). Although this is higher than the percentage of non-afflicted households using this coping strategy (46%), there were no significant differences in income between afflicted and non-afflicted households and other socio-economic differences were not controlled for between the two groups (SADC, 2003).

The Mason et al. (2005) paper is one of the few sources of evidence cited by de Waal that is based on regression analysis. It is also the only study other than the current paper of which we are aware that has explicitly tested for an interaction effect between HIV/AIDS and drought on a food security- or rural livelihoods-related outcome variable. Mason et al. (2005) regressed change in child underweight prevalence (a measure of malnutrition) on a drought year dummy variable, HIV prevalence, and an interaction term between drought and HIV prevalence. The independent effects of HIV prevalence and drought were statistically insignificant but the interaction term was statistically significant and positive, indicating that the effect of drought is exacerbated by high HIV prevalence and vice versa. However, the results of this regression analysis may be biased because no other factors affecting change in child underweight were controlled for in the model.

An oft-cited source of evidence for the NVF hypothesis is anecdotes of increased engagement in transactional sex by women during food crises (SCF, 2002; SAHIMS, 2003; and Semu-Banda, 2003, cited in de Waal, 2007). While such practices may indeed be occurring, there is very little evidence to indicate whether it has increased in recent years (as opposed to people simply becoming more aware of it). Furthermore, even it if is a widespread practice, increased engagement in transactional sex lends credence to the idea that food crises are exacerbating the spread of HIV/AIDS, rather than HIV/AIDS worsening the effects of food crises as postulated by NVF (Bryceson and Fonseca, 2006).

de Waal presents no evidence in support of the third and final NVF sub-hypothesis that the ecology of nutrition and infection changes in poor, vulnerable populations in the presence of a generalized HIV/AIDS epidemic (de Waal, 2007).

Overall, the evidence in support of the various components of the NVF hypothesis is weak at best. This is not to say that the theory is invalid, only that it has yet to be tested empirically in any rigorous way. In this study the use of econometric analysis is a critical contribution, as it allows us (subject to the constraints of the data available) to control for the effects of other processes and identify the *ceteris paribus* effects of HIV/AIDS, rainfall and other shocks, and their interactions on rural livelihoods as measured by mean household value of crop output, value of crop output per hectare and cultivated area. Furthermore, our analysis is based on nationally representative survey data and considers a 13-year period rather than being based on a limited geographic area or short time period.

3. METHODS AND DATA

3.1. Theoretical framework

Household farm supply decisions depend on the available production technology (including random climatic shocks), relative output and input prices faced, and the knowledge and asset base of the household. The knowledge base of the household is a potentially important determinant of farm technical efficiency and so can be thought of as a household supply shift variable (other things equal, more technically efficient households will produce more). The asset base of the household is potentially important because with imperfect credit markets the ability of households to finance input purchases and invest in productive assets will be constrained by available household resources.

More formally, we can think of a household supply function being represented as $Y=f(p_y, \mathbf{p_x}, \mathbf{Z})$, where p_y is the output price, $\mathbf{p_x}$ is a vector of input prices, and $\mathbf{Z}$ is a vector of variables representing the household's knowledge level, their asset base, and other uncontrollable random shocks to the productions process (e.g., rainfall). The effect of HIV/AIDS could influence supply in two main ways. First, by reducing the productivity of household labor HIV/AIDS could in essence alter the production function and shift the supply curve inward. Second, by consuming household assets in caring for the sick, burial expenses, etc, HIV/AIDS could make it more difficult to purchase desired inputs and make desired investments in productive assets, again shifting the supply curve inward. In both cases we can think of the incidence of HIV/AIDS as being one element of the **Z** vector of conditioning variables in the household supply function.

The form of the supply function is of critical importance in testing the NVF hypothesis. An important component of the NVF hypothesis is that the productivity and asset base effects of HIV/AIDS will be exacerbated in times of drought and other forms of household stress. Hence, in order to test this hypothesis effectively the supply functional form must be flexible enough to allow for HIV/AIDS to have a differential effect on household supply depending on the levels of other conditioning variables in the **Z** vector.

3.2. Empirical model

Building on the general output supply function discussed above, we construct the following district-level panel data model:

$$y_{it} = \beta_0 + \beta_1 PPI^e_{it} + \beta_2 FERT_{kt} + \beta_3 IR_{t-1} + \beta_4 AIDS_{it} + \beta_5 AIDS^2_{it} + \beta_6 RAIN_{it} + \beta_7 RAIN^2_{it} + \beta_8 SUB_{it}$$
$$+\beta_9 FEM_{it} + \beta_{10} BUD_t + \beta_{11} AIDS_{it} * RAIN_{it} + \beta_{12} AIDS_{it} * RAIN^2_{it} + \beta_{13} AIDS_{it} * SUB_{it}$$
$$+\beta_{14} AIDS_{it} * FEM_{it} + \beta_{15} AIDS_{it} * BUD_t + \lambda_i + \varepsilon_{it} \quad (1$$

where y_{it} denotes district-level agricultural production outcomes, i.e., mean household cultivated area, and the mean value of household crop output and crop output per hectare for district *i* at time *t*; PPI^e_{it} is the expected agricultural producer price index[9]; $FERT_{kt}$ is the median real provincial fertilizer price per kilogram; IR_{t-1} is the lagged annual real national interest rate; $AIDS_{it}$ is a measure of the current productivity effect of the historical HIV/AIDS epidemic; $RAIN_{it}$ is a measure of the rainfall-related productivity effect; SUB_{it} is the mean household government fertilizer subsidy in kilograms per hectare; FEM_{it} is the percent of female headed households; BUD_t is the real government budget allocation to the agricultural sector (bil ZKw); λ_i is the time invariant district-level unobservables; and ε_{it} is the error term.

3.3. Model estimation and variables

We estimate the model in equation 1 without the interaction terms to measure the effect of HIV/AIDS on agricultural production outcomes initially assuming that the interaction effects are zero. The NVF hypothesis and the household-level studies outlined above suggest that the partial effect of HIV/AIDS on rural livelihoods is negative. In order to test whether HIV/AIDS is exacerbating the negative impacts of drought and others shocks (in this case, structural adjustment-related reductions in government fertilizer subsidies, agricultural sector budget allocations, and female household headship) as predicted by the NVF hypothesis, we interact the *AIDS* variable with *RAIN*, *SUB*, *BUD* and *FEM* and do hypothesis testing using the resulting parameter estimates. We treat female headship as a household shock because evidence suggests that women are disproportionately affected by the HIV/AIDS epidemic (Gillespie and Kadiyala, 2005; UNAIDS, 2006) and that widow-headed households often cultivate less area than households not afflicted by a prime-age death (Chapoto et al., 2006). Furthermore, descriptive studies suggest that AIDS-related mortality exacerbates gender inequalities (Mutangadura, 2005).

The direct and indirect effects of HIV/AIDS on agricultural production outcomes are the key impacts of concern in this paper. It is well understood that empirical results are sometimes sensitive to model specification. We attempt to overcome this problem by doing sensitivity analysis to investigate the robustness of conclusions concerning the NVF hypothesis to alternative model specifications. This approach provides a more robust assessment of the NVF hypothesis and allows the reader to determine how sensitive the results are to differences in model specification. The next several sections describe the different ways in which we model the relationship between AIDS-related morbidity and mortality, exogenous shocks, and agricultural production outcomes[10]; these sections also detail the assumptions underlying each modeling approach.

3.3.1. Modeling the effect of HIV/AIDS on agricultural production outcomes

We use two different variables to model the severity of the HIV/AIDS epidemic in a given district and year: 1) the estimated HIV prevalence rate; and 2) the estimated AIDS-related mortality rate, defined as the number of AIDS-related deaths divided by the total population. The HIV prevalence rate can be thought of as an advanced indicator of the AIDS-related mortality rate, as there is typically a lag of 8-10 years between seroconversion and death in the absence of antiretroviral treatment (Morgan et al., 2002; CGAIHS, 2000; Zaba, Whiteside and Boerma, 2004).[11] The HIV prevalence rate is the estimated

[9] The agricultural producer price index (PPI) was computed from Post Harvest Survey (PHS) data from 1991/2 to 2003/4. For each year and each district, the total value of crop production was computed overall and by crop. Crop-specific weights were calculated by dividing the value of crop production for each crop by the total value of crop production in the district. The agricultural PPI for each district and year was then computed as a weighted combination of agricultural output prices.

[10] We use 'rural livelihood indicators,' 'agricultural production outcomes,' and 'rural farm production' interchangeably throughout the paper to refer to mean household value of crop output, crop output per hectare and cultivated area.

[11] HIV prevalence rates are measured without reference to when people became HIV positive. Based on epidemiological estimates that the mean period between seroconversion and death is 8-10 years, it is likely that the

percentage of the population currently living with HIV/AIDS, and we expect it to reflect the effects of HIV/AIDS-related illness and morbidity on agricultural production outcomes. We expect the AIDS-related mortality rate to reflect the effects of AIDS-related deaths on such outcomes.

There is often a significant time lag between seroconversion and the onset of symptomatic illness and death, as well as a lag between illness and death and the socio-economic impacts of the epidemic. This 'long-wave' nature of HIV/AIDS (Gillespie, 2006; Barnett and Whiteside, 2002) implies that both current and past HIV/AIDS-related morbidity and mortality may be affecting rural livelihoods. To model both the immediate and delayed impacts of HIV/AIDS-related illness and morbidity, we estimate models including the contemporaneous HIV prevalence rate as well as models including contemporaneous and lagged HIV prevalence. We estimate similar models using the AIDS-related mortality rate instead of HIV prevalence to test the relationships between AIDS-related deaths and agricultural outcomes.

Including numerous lags of the HIV/AIDS variables creates potential problems with multicollinearity and degrees of freedom. To address this issue, we estimate models using a polynomial distributed (Almon) lag structure for the HIV/AIDS variables in addition to models with a traditional distributed lag structure. To identify an appropriate number of years to lag the HIV/AIDS variables in the Almon and traditional distributed lag models (J), we follow the recommendations in Pindyck and Rubinfeld (1997) and Guajarati (2003) and add additional lags until the Akaike Information Criteria (AIC) stops declining. In the Almon lag structures, we impose a second-degree (quadratic) form on the polynomial. That is, we assume in $\sum_{j=0}^{J} \alpha_j HIV_{it-j}$, that α_j can be approximated by $\alpha_j = a_o + a_1 j + a_2 j^2$, where HIV_{it} is the HIV prevalence rate or AIDS-related mortality rate in district i in year t, and j is the length of the lag. Substituting in for α_j, we obtain:

$$HIV_{it}^{*} = \sum_{j=0}^{J} \alpha_j HIV_{it-j} = a_0 \sum_{j=0}^{J} HIV_{it-j} + a_1 \sum_{j=0}^{J} jHIV_{it-j} + a_2 \sum_{j=0}^{J} j^2 HIV_{it-j} \quad (2) \qquad \text{or}$$

$$HIV_{it}^{*} = a_0 Z_{1it} + a_1 Z_{2it} + a_2 Z_{3it} \text{ where } Z_{1it} = \sum_{j=0}^{J} HIV_{it-j},\ Z_{2it} = \sum_{j=0}^{J} jHIV_{it-j},\ Z_{3it} = \sum_{j=0}^{J} j^2 HIV_{it-j} \quad (3)$$

Such a lag structure allows the impact of the HIV prevalence rate in year t to grow over time to a peak (as the disease progresses and ultimately results in the death of the HIV-positive individuals reflected in that HIV prevalence rate in year t) and then for the effect to eventually diminish as the households and communities affected by that wave of illness and death eventually recover.[12] The implications of such a lag structure on the AIDS-related mortality variable are similar. In addition to estimating models with the 'preferred' (i.e., lowest AIC) lag structure for each agricultural production outcome, we estimate models using a seven-year Almon lag, as this is the longest lag structure we can accommodate with the available HIV/AIDS data.[13]

3.3.2. Modeling the effect of rainfall on agricultural production outcomes

Smallholder agriculture in Zambia is predominately rainfed; therefore, we expect rainfall to have an important effect on agricultural productivity as measured by the mean household value of crop output overall and per hectare. The best district-level rainfall data available for our period of analysis, i.e., the 1991/2-2002/3 agricultural years, is mean annual rainfall.[14] Given these data, we model the productivity

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HIV prevalence rates are computed based on people that have been HIV positive for the mean of this period (4-5 years). Therefore, it is likely that HIV prevalence rates are an advance predictor of AIDS deaths with a lag of roughly 4-5 years.

[12] Note that this lag structure allows for any quadratic lag weight path, i.e., either concave or convex. The pattern described above is the intuitively expected result.

[13] In cases where the seven-year Almon lag or contemporaneous HIV/AIDS variable only is the 'preferred' lag structure, we also estimate a 'second-best' lag structure, based on the second lowest AIC result.

[14] Other measures of rainfall, such as the rainfall levels during the key crop-producing months (early October to late April) would be preferable, but are not available for the entire period of analysis. Furthermore, while the productivity effect of rainfall is clearly linked with other factors, such as potential evapotranspiration and soil water retention, sufficient district-level data were not available on such factors.

effect of rainfall in three ways. First, we use mean annual rainfall levels (millimeters) and levels squared. This type of model assumes that it is the amount of rainfall that best determines agricultural production and that the relationship may be non-linear.

Second, following Hoddinott (2006), we use percentage positive and negative rainfall deviations (linear and squared) from the 20-year district mean rainfall level as another way to model the relationship between agricultural production outcomes and rainfall. This allows us to test for differential impacts of negative rainfall shocks (droughts in the extreme) and positive rainfall shocks (floods in the extreme) and their interactions with HIV/AIDS on agricultural production outcomes. Measuring these deviations relative to the long-term *district* average, however, may 'wash-out' the cross-sectional variability in the data as our unit of observation is the district. For this reason, we use a third representation of the potential relationship between rainfall and agricultural production outcomes: the percentage positive and negative rainfall deviations (linear and squared) from the long-term *national* mean level.

The various combinations of HIV/AIDS lag structures and rainfall variables estimated for each agricultural production outcome as well as the associated AIC values are presented in Table 1.

Table 1. Models estimated by HIV/AIDS lag structure, rainfall variable, and dependent variable

HIV/AIDS measure	Rainfall measure	Lag structure and Akaike Information Criteria								
		Crop output			Crop output per hectare			Cultivated area		
HIV	Annual	D t-1 (8349)	t only (8357)	†A t-7 (8341)	†A t-4 (7960)	t only (7969)	A t-7 (7962)	†A t-4 (64)	t only (78)	A t-7 (78)
	Dist. dev.	†A t-3 (8332)	t only (8365)	A t-7 (8353)	†A t-3 (7974)	t only (7997)	A t-7 (7988)	A t-6 (86)	t only (84)	†A t-7 (83)
	Natl. dev.	†D t-5 (8291)	t only (8348)	A t-7 (8334)	†A t-3 (7921)	t only (7936)	A t-7 (7938)	†D t-5 (42)	t only (82)	A t-7 (80)
AIDS	Annual	D t-1 (8356)	t only (8352)	†A t-7 (8334)	D t-1 (7962)	t only (7968)	†A t-7 (7955)	†D t-1 (79)	t only (87)	A t-7 (86)
	Dist. dev.	†D t-5 (8302)	t only (8364)	A t-7 (8351)	†D t-7 (7942)	t only (7995)	A t-7 (7990)	†A t-3 (73)	t only (92)	A t-7 (91)
	Natl. dev.	†D t-7 (8281)	t only (8344)	A t-7 (8323)	†D t-7 (7884)	t only (7942)	A t-7 (7928)	†A t-3 (75)	t only (91)	A t-7 (90)

Source: Authors' calculations
Notes: HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. Akaike Information Criteria values in parentheses. † indicates the lowest AIC lag structure for the given HIV/AIDS-rainfall-dependent variable combination, i.e., the 'preferred' lag structure.

3.3.3. Controlling for other factors that may affect agricultural production outcomes

Expected crop output prices (PPI^e_{it}) are a major influence on farmers' planting decisions (Nerlove, 1958). Two reasonable models of price expectations in the Zambian smallholder sector are naïve expectations and adaptive expectations.[15] The input prices that are likely to influence rural farm production are the price of fertilizer ($FERT_{kt}$) at the time of planting and the price of credit, i.e., the lagged real interest rate (IR_{t-1}). (Agricultural and industrial wage rates would have also been appropriate to include as input prices but such data were not available for the entire period of analysis.) Finally, as there may be unobserved factors that are growing over time that affect agricultural production outcomes, such as infrastructure or agricultural technology improvements, we also evaluate the performance of models including a time trend variable.

[15] Rational expectations may not be an appropriate model of price expectations in this context because it requires that smallholders have information about the demand curve they face for their output. Such information is typically not available to Zambian smallholders. The naïve and adaptive models of price expectations assume less information is available to the decision makers. In the naïve expectations model, expected output price (p^e_{it}) is defined as $p^e_{it} = p_{it-1}$, where p_{it-1} is the observed price in the previous period. In the adaptive expectations framework, expected output price is defined as $p^e_{it} = \alpha p^e_{it-1} + (1-\alpha) p_{it-1}$ where $0 < \alpha < 1$.

3.3.4. Estimation

The characteristics of the various models outlined above require different estimation techniques. All of the models we estimate are panel data models and each includes error terms embodying the unobserved factors. We take advantage of the panel-nature of the data and use estimation techniques that allow us to difference out the district-level unobserved effects that do not vary over time (λ_i). In models in which we assume farmers' price expectations to be naïve, we use the fixed effects estimator. This is appropriate because all of the regressors are strictly exogenous. In models in which we assume farmers' price expectations to be adaptive, however, the strict exogeneity of regressors assumption of fixed effects fails because of the inclusion of a lagged dependent variable in the model (Wooldridge, 2002). Therefore, we estimate these models using the Arellano-Bond technique (Arellano and Bond, 1991). We find evidence of heteroskedasticity and serial correlation in the error terms in both the naïve and adaptive expectations models. To correct for this, we use fixed-effects GLS to estimate the naïve expectations models and one-step heteroskedasticity-robust and two-step Arellano-Bond estimation for the adaptive expectations models (Wooldridge, 2002).

3.4. Data

The analysis in this paper is based on data from a number of different sources. Annual district-level data on smallholder agricultural production, government fertilizer subsidies, and producer price indexes are drawn from the annual Post-Harvest Surveys (PHS) of small and medium scale holdings for the 1991/2 to 2003/4 agricultural years. The PHS is a nationally representative longitudinal survey of 52 districts. Approximately 7,000 small and medium scale farming households[16] are included in the PHS each year; however, the specific households surveyed are not the same from year to year; hence, the district (i.e., not the household) is our cross-sectional unit of observation. The PHS is carried out by the Central Statistical Office (CSO) in conjunction with the Ministry of Agriculture and Cooperatives (MACO) and Michigan State University's Food Security Research Project. For more details about survey design and sampling procedures see Megill (2004).

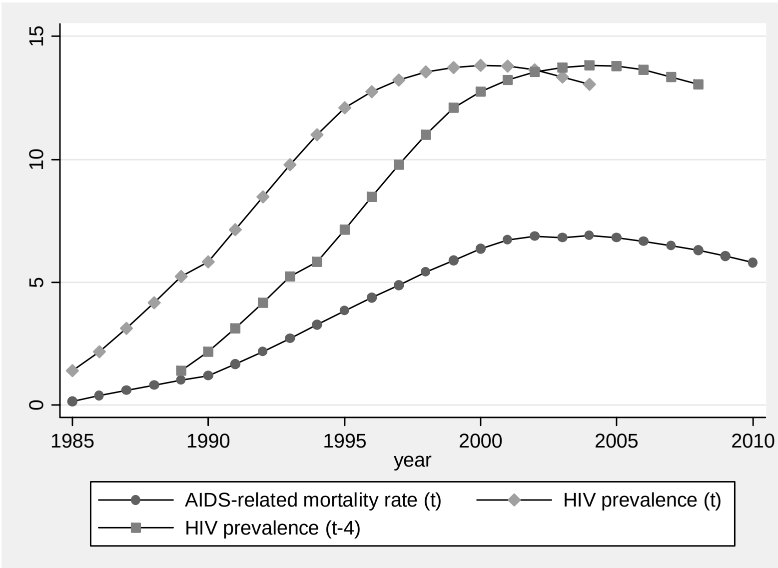
Estimates of district HIV prevalence and AIDS-related mortality rates are drawn from the report, *Zambia: HIV/AIDS Epidemiological Projections, 1985-2010* (CSO, 2005) and the Zambian population censuses from 1980, 1990, and 2000 (CSO, 1975; CSO, 1985; CSO, 1994; CSO, 2003). The Epidemiological Projections report lists estimated HIV prevalence rates and numbers of AIDS-related deaths for each district for the years 1985, 1990, 1995, and 2000-2010; extrapolation was required to estimate the HIV prevalence and AIDS deaths in the years for which no values were reported. To control the number of AIDS deaths for population growth, we computed a variable for the "AIDS-related mortality rate", defined as the number of AIDS-related deaths divided by the total population. As with the HIV prevalence and AIDS deaths figures, some extrapolation was required to estimate population figures for the years in the intercensal periods.

Median provincial fertilizer prices are based on data from the MACO Agricultural Marketing Centre. Real interest rates are from *World Development Indicators, 2005* (World Bank, 2005). Finally, rainfall data are from 36 rainfall stations throughout Zambia. Summary statistics, correlation matrices and other information on the variables used in the analysis are included in the Appendix.

One important result to note is the high correlation ($\rho = 0.90$) in our sample between the estimated district level HIV prevalence and the contemporaneous estimated AIDS-related mortality rate. Because of the lag between seroconversion and AIDS-related death, the correlation between the AIDS-related mortality rate and HIV prevalence increases as we lag HIV prevalence (Table 2). This correlation is highest ($\rho \approx 0.95$) between the AIDS-related mortality rate in year t and the HIV prevalence rate from three to five years earlier (see Table A4 in the Appendix for a table of these correlations). The relationship between mean district HIV prevalence and lagged mean district AIDS-related mortality is depicted in Figure 1.

[16] Small and medium-scale farming households are defined as those households that cultivate fewer than 20 hectares of land and produce crops, raise livestock or poultry, or farm fish. We refer to these households as 'smallholder' households throughout the text.

Figure 1. Mean district estimated HIV prevalence and AIDS-related mortality, Zambia



Source: Based on raw data from *Zambia: HIV/AIDS Epidemiological Projections: 1985-2010* (CSO, 2005) and Zambian population census data (CSO, 1975; CSO, 1985; CSO, 1994; CSO, 2003)

These relationships between HIV prevalence and lagged AIDS-related mortality are consistent with *a priori* expectations and the epidemiology of HIV/AIDS. In general, the time from seroconversion to death is 8-10 years. So, for any given HIV-positive population, on average, individuals have been living with HIV for 4-5 years. The high correlation in the Zambia data between HIV prevalence from 3-5 years ago and AIDS-related deaths today roughly corresponds with the average time period for an HIV-positive individual to die of AIDS-related causes.

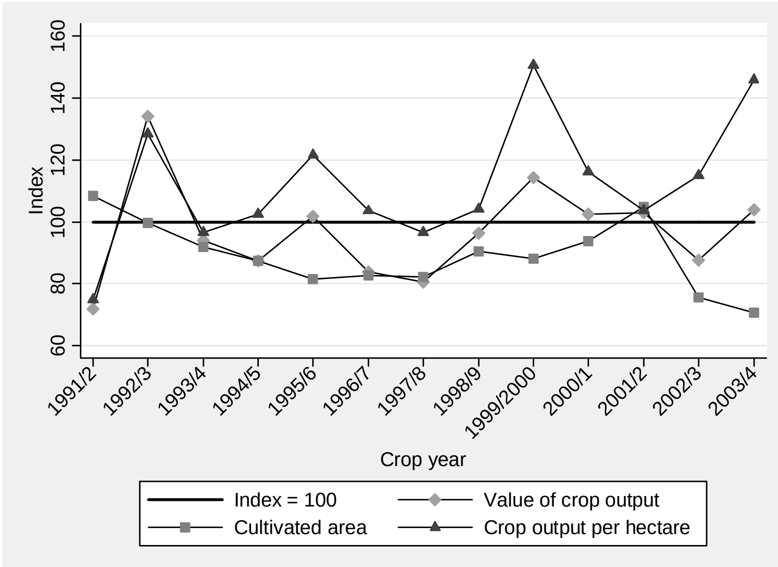
4. RESULTS

4.1. Trends in agricultural production outcomes

Prior to carrying out the econometric modeling, we first conducted descriptive and time trend analysis of national and provincial trends in mean household cultivated area, value of crop output, and value of crop output per hectare.[17] (We would also want to track indicators of household consumption and full incomes, but the surveys did not contain the data to construct these.) Analysis of national trends in agricultural production outcomes suggests that, although these outcomes fluctuated during the period 1991/2-2003/4 (Figure 2), there were no statistically significant increasing or decreasing trends in any of these indicators (Table 2).

[17] For the complete details of this analysis of trends in agricultural production outcomes in Zambia, see Mason et al., 2007.

Figure 2. National trends in mean household agricultural production outcomes, 1991/2-2003/4



Source: Based on raw data from PHS surveys, Central Statistical Office, Lusaka.
Notes: Indexed to the average of the 1991/2, 1992/3 and 1993/4 crop years.

Table 2. OLS regression results: national trends in mean household agricultural production outcomes

	Dependent variable		
	Cultivated area (ha)	Crop output (10,000 ZKw)	Crop output per hectare (10,000 ZKw/ha)
Time trend	0.142	-0.599	2.113
	(1.00)	(0.07)	(0.35)
Time trend, squared	-0.009	0.090	0.033
	(1.12)	(0.15)	(0.08)
Constant	0.889	146.078***	90.653***
	(1.58)	(5.62)	(4.92)
Observations	12	13	13

Source: Based on raw data from PHS surveys, 1991/2-2003/4, Central Statistical Office, Lusaka.
Notes: These results are from ordinary least squares (OLS) estimation of $y_t = \beta_o + \beta_1 t + \beta_2 t^2 + \varepsilon_t$, where y_t is the national-level agricultural production outcome, t is a time trend and ε_t is the error term. Absolute value of t statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

The gross value of crop output and crop output per hectare are more directly affected by rainfall than is cultivated area; hence, we see more fluctuation in the crop output-related outcomes, with low production and yield periods corresponding to drought years (e.g., 1991/2, 1993/4, 1997/8 and 2001/2). Mean household cultivated area declined gradually through the mid-1990s, the period of peak implementation of structural adjustment reforms. Cultivated area reached a local minimum in 1995/6, subsequently increased up until 2001/2 but dropped off sharply thereafter. It will be important to analyze trends in mean household cultivated area beyond 2003/4 as data become available. The NVF hypothesis grew, in part, out of the devastating effects of the 2001/2 southern African drought, the exact year after which we see a steep decline in mean household cultivated area in Zambia. If this trend continues after 2003/4, this might lend support to the NVF hypothesis that the generalized HIV/AIDS epidemic is eroding rural livelihoods. In contrast to the drop off in cultivated area between 2001/2 and 2003/4, mean household value of crop output and output per hectare sharply increased from 2002/3 to 2003/4 as the rains returned after the 2001/2 drought. Although households may have cultivated less land in 2003/4 than in 2001/2, it appears that productivity (output per hectare) increased substantially in that period, enough to offset the declines in area planted. Overall, national trends in mean household agricultural production outcomes in Zambia from 1991/2 to 2003/4 do not suggest an unambiguous decline in rural farm production during that period.

Similar analyses were conducted at the provincial level. Like the national level trends, the provincial level trends do not suggest an unequivocal decline in rural livelihoods among Zambian smallholders as measured by mean household crop output, output per hectare and cultivated area. The patterns are heterogeneous at the provincial level, with agricultural production outcomes declining in some provinces or remaining steady or rising in others. Although this trend analysis sheds some light on overall patterns in agricultural production outcomes in Zambia, it tells us nothing about the specific impacts of HIV/AIDS and other factors on rural farm production. In order to estimate these effects, econometric methods are required.

4.2. Direct effects of HIV/AIDS on agricultural production outcomes

We estimate models of the form in equation 1 excluding the interaction terms to get an initial measure of the effects of HIV/AIDS on mean household value of crop output, output per hectare, and cultivated area. *A priori*, based on the results of household- and community-level studies of the socio-economics impacts of the epidemic (e.g., those reviewed in Gillespie and Kadiyala, 2005), we expect the partial effect of an increase in the district HIV prevalence or AIDS-related mortality rate on these agricultural production outcomes to be negative, *ceteris paribus*. However, based on the econometric analysis described in section 3, we find little evidence of such a negative effect on the average Zambian smallholder's agricultural production outcomes.[18] (Due to the large number of models estimated and space limitations, we report only the parameter estimates for the key variables of interest, rather than the full regression results.)

4.2.1. Partial effect of HIV/AIDS on mean household value of crop output

Considering first the long-run partial effect of an increase in district HIV prevalence, estimation results from the 'preferred' (i.e., lowest AIC) lag structure for each of the types of rainfall models (i.e., mean annual rainfall, and positive and negative percentage deviations from the district or national long-term average rainfall) suggest that the partial effect of a one percentage point increase in mean district HIV prevalence on mean household value of crop output is not statistically different from zero[19] (Table 3). In the case of the mean annual rainfall model specification, this partial effect is negative and statistically significant ($p<0.05$) when HIV prevalence is high (i.e., evaluated at the 90th percentile of HIV prevalence): given a one percentage point increase in HIV prevalence, predicted mean household value of crop output declines by approximately 4.5%. These results, however, are very sensitive to the lag structure used for HIV prevalence: if we use only the contemporaneous HIV prevalence, the long-run partial effect of an increase in HIV prevalence is significantly positive (+1.3% to +3.5%) ($p<0.01$). When we use a seven year Almon lag of HIV prevalence, the long-run partial effect is negative and significant ($p<0.05$) or not statistically different from zero.

The long-run partial effect of an increase in the district AIDS-related mortality rate is similarly sensitive to model specification, but in no model specifications do we find evidence of a negative effect of AIDS-related deaths on mean household value of crop output. The partial effect of a one percentage point increase in the contemporaneous mean AIDS-related mortality rate is positive (+3.7% to +6.9%) and highly significant ($p<0.01$). For the 'preferred' lag structures, this partial effect is not statistically different from zero in the model specifications using positive and negative rainfall shocks, but it significantly positive (+6.6%, $p<0.01$) in the model using mean annual rainfall.

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[18] We report here only on the results of the models in which we assume smallholders' price expectations to be naïve. Estimation of dynamic models where we assumed those expectations to be adaptive proved problematic as this involved lagging previously lagged variables, and resulted in numerous terms being dropped due to collinearity.

[19] At the 10% significance level. When results are reported as 'not statistically different from zero', this is meant to imply statistical insignificance at the 10% level even though the significance level not explicitly stated.

Table 3. Long-run partial effects of HIV/AIDS on mean household crop output ('000 ZKw)

HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
HIV	Annual	t only	35.158***	28.699***	18.580*	17.229***
		D t-1	-26.346*	-41.039**	-17.976	-21.464
		† A t-7	-5.378	-59.049**		
	Dist. dev.	t only	38.201***	37.561***	17.526*	25.526***
		† A t-3	25.174	7.043		
		A t-7	-3.902	-49.811**		
	Natl. dev.	t only	45.154***	37.560***	28.572***	26.451***
		† D t-5	16.246	-12.275		
		A t-5	13.313	-33.831		
		A t-7	5.839	-47.262***	9.887	-47.620***
AIDS	Annual	t only	90.364***	60.294***	54.009***	37.241***
		D t-1	91.286***	61.948***	33.469	44.867****
		†A t-7	86.280***	7.471	16.231	-22.722
	Dist. dev.	t only	88.610***	61.566***	48.131***	34.337***
		† D t-5	45.010	52.545*	-15.178	26.328
		A t-5	81.223***	-78.325	1.894	-117.818
		A t-7	88.402	15.297	8.580	-15.780
	Natl. dev.	t only	87.970***	58.092***	66.100***	44.479***
		† D t-7	-3.014	-34.917	-59.052	-55.965
		A t-7	84.250***	16.709	13.345	-15.660

Source: Authors' calculations

Notes: Partial effect of a one percentage point increase in the HIV prevalence rate or AIDS-related mortality rate on mean household value of crop output. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant. The mean household value of crop output for the entire sample is 1,304,146 ZKw per year.

Although the estimated partial effect of HIV/AIDS on the mean household value of crop output in the results described above is quite sensitive to model specification, the partial effects of the other explanatory variables in the models (e.g., rainfall, prices, policy variables) are more consistent across models. The partial effect of an increase in the lagged agricultural producer price index (PPI) is either not statistically different from zero or is positive (+6.8% to +8.2%) and significant ($p<0.01$), depending on the model specification. This is consistent with *a priori* expectations that given an increase in producer prices in the previous year, we would expect smallholders to increase their crop output in the current period; however, crop production is a weaker indication of supply response than is cultivated area (Nerlove, 1958; Askari and Cummings, 1977). The results for the rainfall variables are also consistent with theory: the linear rainfall terms have a positive coefficient while the squared terms have a negative coefficient. In other words, at 'average' rainfall levels, rainfall has a generally positive effect on mean household value of crop output, but at the extremes, this effect becomes less positive and eventually negative (as in the case of droughts or floods). The partial effect of an increase in the lagged real interest rate is consistently significantly negative ($p<0.01$, -0.2% to -0.7%) but the effect is small in magnitude. The partial effect of an increase in the fertilizer subsidy is positive (+0.2% to +0.9%) and significant ($p<0.01$), but this effect is also small in magnitude. Increases in the percentage of female-headed households and the agricultural sector budget have no statistically significant effect on mean household value of crop output in the majority of models estimated. One result that is contrary to *a priori* expectations is the consistently positive and significant ($p<0.1$) coefficient on fertilizer price. The partial effect of a 10% increase in the mean fertilizer price is a 1.02% to 2.45% increase in predicted mean household value of crop output.

4.2.2. Partial effect of HIV/AIDS on mean household value of crop output per hectare

Results regarding the long-run partial effect of HIV/AIDS on mean household value of crop output per hectare are ambiguous, as was the case for the partial effects on value of crop output outlined above. In models using the 'preferred' lag structure, the partial effect of a one percentage point increase in the mean district estimated HIV prevalence rate on mean household value of crop output per hectare is either not statistically different from zero or is positive (+3.5% to +5.8%) and highly significant ($p<0.01$) (Table 4). In models using the contemporaneous HIV prevalence rate, this partial effect is also positive (+2.0% to +3.5%) and statically significant ($p<0.01$) across all rainfall representations. If we lag HIV prevalence up to seven years, the long-run partial effect of an increase in HIV prevalence is not statistically different from zero in most models. Thus, these results are quite sensitive to the lag structure used for the HIV prevalence variable.

For models in which we use the district AIDS-related mortality rate instead of HIV prevalence, the results are similarly ambiguous but in some cases are more consistent with *a priori* expectations. In models using the preferred lag structure, the partial effect of a one percentage point increase in the mean district AIDS-related mortality rate on mean household crop output per hectare is either not statistically different from zero, or is negative (-6.8% to -7.4%) and significant ($p<0.05$). However, if this partial effect is evaluated at a high AIDS-related mortality rate (i.e., the 90th percentile), the effect is negative (-5.9% to -10.2%) and significant ($p<0.05$) in models using rainfall deviations.

Table 4. Long-run partial effects of HIV/AIDS on mean household crop output per hectare ('000 ZKW/ha)

HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
HIV	Annual	t only	25.192*	17.917***	19.814***	13.165
		† A t-4	4.178	11.664		
		A t-7	-2.654	-5.405		
	Dist. dev.	t only	29.012***	26.231***	20.772***	19.158**
		† A t-3	35.821**	38.574**		
		A t-7	3.062	-2.685		
	Natl. dev.	t only	32.572***	25.834***	28.596***	22.578**
		† A t-3	57.933***	53.731***	58.813***	45.410***
		A t-7	9.555	5.432	21.878*	-0.770
AIDS	Annual	t only	38.858***	16.688**	16.421	4.007
		D t-1	46.062***	7.322		
		†A t-7	35.219	-6.939	3.821	-21.626
	Dist. dev.	t only	45.919***	19.454***	16.387	2.085
		† D t-7	-9.809	-71.436**	-75.657**	-103.596***
		A t-7	50.976**	4.278	5.213	-15.025
	Natl. dev.	t only	41.066***	17.477**		
		† D t-7	-35.728	-60.208**	-69.058**	-76.864***
		A t-7	32.018	3.977		

Source: Authors' calculations

Notes: Partial effect of a one percentage point increase in the HIV prevalence rate or AIDS-related mortality rate on mean household value of crop output per hectare. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant. The mean household value of crop output per hectare for the entire sample is 1,015,998 ZKw per hectare per year.

As in the case of mean household value of crop, the partial effects of the other explanatory variables (rainfall, prices, etc.) are robust to model specification in models where mean household value of crop output per hectare is the dependent variable. The signs, significance levels, and magnitudes of the partial effects of these control variables are also similar to the crop output results, with the exception of the partial effect of lagged PPI. Whereas we found this effect to be zero or slightly positive in the case of crop output, the partial effect on crop output per hectare is zero or negative and significant ($p<0.10$); however, this effect is quite small in magnitude (-0.3% to -0.6%).

4.2.3 Partial effect of HIV/AIDS on mean household cultivated area

Of the three agricultural production outcomes considered, the results for the partial effect of HIV/AIDS on mean household cultivated area are most consistent with *a priori* expectations. In models in which mean district estimated HIV prevalence is used to measure the severity of the HIV/AIDS epidemic, the partial effect of a one percentage point increase in this prevalence is not statistically different from zero. However, if this partial effect is evaluated at high HIV prevalence, we find a negative (-1.3% to -5.7%) and statistically significant ($p<0.01$) effect in many of the models specifications (Table 5).

Results are more sensitive to model specification when we use the estimated AIDS-related mortality rate to measure the productivity effects of the HIV/AIDS epidemic. The partial effect of a one percentage point increase in the contemporaneous mean AIDS-related mortality rate is positive (+3.5%) and statistically significant ($p<0.01$). Results for the preferred lag structure models are similar, although the range of positive effects is larger (+3.6% to +6.3%). If we lag the AIDS-related mortality rate up to seven years, the long-run partial effect on mean household cultivated area is not statistically different from zero.

Table 5. Long-run partial effects of HIV/AIDS on mean household cultivated area (ha)

HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
HIV	Annual	t only	.001	-.008	-.010	-.018
		† A t-4	-.0636***	-.0843***		
		A t-7	-.00519	-.0512***	-0.0168	-.0456***
	Dist. dev.	t only	.004	-.006	-.008	-.017
		A t-6	-.00319	-.0485***		
		† A t-7	-.00276	-.0500***		
	Natl. dev.	t only	.002	-.008	-.010	-.018**
		† D t-5	-.0211	-.0763***		
		A t-5	-.00294	-.0526***		
		A t-7	-.00524	-.0528***	-.0171	-.0477***
AIDS	Annual	t only	.046***	.041***		
		† D t-1	.0490***	.0732***	-.00181	.0543***
		A t-7	.0217	.0165	-.0318	-.0111
	Dist. dev.	t only	.048***	.044***		
		† A t-3	.0844***	.0721***	.0617***	.0624***
		A t-7	.0290	.0217	-.0269	-.00801
	Natl. dev.	t only	.046***	.042***		
		† A t-3	.0797***	.0690***		
		A t-7	.0220	.0161	-.0315	-.0112

Source: Authors' calculations

Notes: Partial effect of a one percentage point increase in the HIV prevalence rate or AIDS-related mortality rate on mean household cultivated area. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant. The mean household cultivated area for the entire sample is 1.347 hectares per year.

Although the estimated partial effect of HIV/AIDS on mean household cultivated area is sensitive to model specification, the other partial effects are more robust. We find no evidence of a supply response to increases in the agricultural PPI. As anticipated, rainfall has little significant effect on area cultivated – we expect rainfall to affect the amount of crop output to a much greater extent than cultivated area. As in the case of mean household value of crop output, the estimated partial effect of an increase in the fertilizer price is positive and significant ($p<0.10$). The partial effect of an increase in the real interest rate is negative and significant ($p<0.01$) but quite small in magnitude (-0.2% to -0.6%). Likewise, the partial effect of an increase in fertilizer subsidies is positive and significant ($p<0.10$) but of little practical significance as it is less than 0.07%. An increase in the percentage of female-headed households in the district has either zero partial effect on cultivated area or a small negative (less than -0.2%) and significant effect ($p<0.10$). Finally, although the estimated partial effect of a 10% increase in the mean agricultural sector budget is negative and significant ($p<0.01$), this effect is extremely small in practical terms (less than -0.084%).

4.2.4. Discussion

Table 6 summarizes the estimated direct effects of HIV/AIDS on rural farm production.

Table 6. Summary of direct effects of HIV/AIDS on mean rural household farm production

Agricultural production outcome	HIV/AIDS measure	Lag structure		
		t only	Preferred	A t-7
Crop output	HIV prevalence	(+)	0 or (-)	0 or (-)
	AIDS-related mortality	(+)	0 or (+)	0 or (+)
Crop output per hectare	HIV prevalence	(+)	0 or (+)	0 or (+)
	AIDS-related mortality	0 or (+)	0, (+), (-)	0
Cultivated area	HIV prevalence	0	0 or (-)	0 or (-)
	AIDS-related mortality	(+)	0 or (+)	0

Source: Authors' calculations

Notes: (+) = statistically significant, positive effect; (-) = statistically significant, negative effect; 0 = effect not statistically different from zero. A t-7 = Almon lag with maximum lag length of 7 years; t only = Contemporaneous only; Preferred = preferred (lowest AIC) lag structure.

Although the results are sensitive to model specification, we find some evidence of a weak negative relationship between *lagged* HIV prevalence and mean household value of crop output and cultivated area. Other household-level studies have also found negative but weak impacts of AIDS-related mortality on household crop output and labor use in agriculture (e.g., Larson et al. 2004; Beegle, 2005). The difference between the results for lagged HIV prevalence and the statistically significant positive partial effect of contemporaneous HIV prevalence on these agricultural production outcomes underscores the importance of considering both the immediate and delayed impacts of HIV prevalence. The statistically significant negative partial effect of HIV prevalence on crop output and cultivated area is consistent with numerous household level studies that have found evidence of negative impacts of HIV/AIDS on smallholder households. The fact that in other cases we find no statistically significant effect may be related to our unit of observation being the district level. In looking at the mean household agricultural production outcomes at the district level, we necessarily gloss over the complex dynamics occurring among affected and non-affected households. While some households may be negatively impacted by the epidemic, others may benefit from their neighbors' losses, e.g., in terms of acquiring their land or assets. On balance at the district level, these effects may 'cancel' each other out. Where we find evidence of a positive effect of an increase in HIV prevalence on cultivated area or crop output, it may be that, at the district level, those that are acquiring land and other assets as a result of the epidemic may be producing more from it than those that are losing these assets.

It is also important to bear in mind that we are looking at the impacts of HIV/AIDS on the *smallholder* sector. Some studies (Topouzis, 1999) suggest that HIV/AIDS is causing households that were engaged in larger-scale and/or cash crop agriculture to revert to smaller-scale or subsistence production. If such households were above the 20 hectare threshold that defines the smallholder sector prior to being affected by HIV/AIDS, but were then forced to reduce their area cultivated or production, such households might be pushed into the smallholder category and, if there were enough such households, this could be reflected in a positive coefficient on HIV prevalence.

We find some evidence of a weak positive partial effect of increases in HIV prevalence on mean household value of crop output per hectare. This is inconsistent with household level studies that suggest that affected households cultivate fewer high value crops and devote a greater portion of their land to cereals than non-affected households (Yamano and Jayne, 2004; du Guerny, 2002); however, even if households are cultivating less area due to the epidemic, they may also be cultivating that area more intensely. Or, considering again households that may have been pushed below the 20-hectare smallholder threshold, these households may be producing more high value crops. It is also possible that the non-affected households that are benefiting from their neighbors' losses might be more productive than the households from which they gained land, assets, etc., again resulting in an increase in crop output per hectare.

Another potential explanation is that we may not be adequately 'holding other factors fixed' in our regression analysis. Data that covers the entire 13-year period of analysis is extremely limited, and data on wages, district-level input prices, and other factors that could be affecting agricultural production outcomes are not available. We also are not able to include a variable that directly controls for agricultural technology improvements. While the time trend is included as a crude proxy for technological change, the pattern of agricultural technology adoption often follows an S-shaped curve – a shape very similar to a typical epidemic curve (Rogers, 2003; Griliches, 1957) (also refer to Figure 1). That is, since we are not able to explicitly control for agricultural technology adoption, its (most likely positive) effect may be captured by the HIV prevalence effect, as the two variables may be highly correlated or, in the least, follow similar patterns over time. Given the data available, it is not possible to test these various explanations and it is indeed surprising that we would find some evidence of a positive causal effect of rising HIV prevalence rates on agricultural production outcomes.

The partial effect of an increase in the AIDS-related mortality rate on mean household cultivated area and value of crop output per hectare is estimated to be zero or positive while the partial effect on mean household value of crop output is even more sensitive to model specification, with results ranging from negative and significant to positive and significant. Models in which we lag the AIDS-related mortality rate capture the immediate effect of AIDS-related deaths and the effect during the first several years after the death. One possible explanation for the positive and significant results could be that we are capturing the "recovery" of households after suffering an AIDS-related death. There may also be significant measurement error in the AIDS-related mortality rate variable as it based not only on *estimated* AIDS-related deaths but also on *estimated* population levels drawn from census data.

Of the three mean household agricultural production outcomes analyzed in this paper, mean household cultivated area likely has the fewest problems with measurement error. To compute the 'household value of crop output', which is then aggregated up to the district level, we combine the gross value of production of 17 different types of crops. The raw data are recall data (from Post-Harvest Surveys), and thus there are likely issues with respondents over- or under-reporting actual production levels. This may be less of an issue with cultivated area, i.e., households are likely more accurate in their recollections of how many hectares they planted overall than they are in their recollections of how many kilograms of each of 17 crops they harvested.

4.3. *Indirect effects of HIV/AIDS on agricultural production outcomes*

The key component of the new variant famine hypothesis that makes it 'new' is the prediction that the generalized HIV/AIDS epidemic in southern Africa exacerbates the effects of exogenous shocks on rural livelihoods. Drought is the most often cited shock that de Waal and others suggest will have more negative effects on highly AIDS-affected households and communities; other shocks that we might expect to be exacerbated by HIV/AIDS include floods, policy changes such as those that occurred as part of structural adjustment reforms, and gender inequalities. In this section we detail the estimation results from models of the form in equation 1 that include interaction terms between HIV/AIDS, rainfall, policy shocks, and the percentage of female-headed households. As is evident in equation 1, the partial effect of fertilizer subsidies, for example, on the agricultural production outcome of interest is not only the coefficient on the fertilizer subsidy variable itself but also depends on the level of HIV prevalence or AIDS-related mortality. That is, from equation 1,

$$\partial \hat{y} / \partial SUB = \hat{\beta}_8 + \hat{\beta}_{13} AIDS \qquad (4)$$

where $\hat{y}$ is the predicted agricultural production outcome of interest, *SUB* is the mean household government fertilizer subsidy in kilograms per hectare, $\hat{\beta}_8$ is the estimated coefficient on *SUB*, *AIDS* is the estimated district HIV prevalence or AIDS-related mortality rate, and $\hat{\beta}_{13}$ is the estimated coefficient on the *AIDS*SUB* interaction term. (Similar partial derivatives can be taken with respect to rainfall, agricultural sector budget, and female-headed households.) To examine the impact of HIV/AIDS on the partial effect of fertilizer subsidies, for example, we perform different 'simulations' in which we evaluate the partial derivative in equation 4 at mean and high (i.e., the 90th percentile) HIV/AIDS levels and compare the results. If the partial effect is positive when evaluated at mean HIV/AIDS levels but less positive in magnitude when evaluated at high HIV/AIDS levels, then there is a negative interaction between HIV/AIDS and fertilizer subsidies – fertilizer subsidies have less of a positive impact on agricultural production in highly AIDS-affected areas. Similarly, if the partial effect is negative when evaluated at mean HIV/AIDS and 'more negative' when evaluated at high HIV/AIDS, then there is evidence that HIV/AIDS exacerbates the negative effect of a shock. We perform this analysis for each of the 'shocks' that are interacted with HIV/AIDS in equation 1. (Due to the complexity and number of models estimated in the analysis, as well as space limitations, we present the results of the simulations described above rather than the raw regression results.)

4.3.1. Evidence that HIV/AIDS exacerbates the effects of drought?

In the context of equation 1, we can explore the effects of drought on crop output, for example, by examining the partial derivative of crop output with respect to high negative rainfall shocks (i.e., negative rainfall shocks at the 90th percentile = 26.819%) and evaluate this partial derivative at mean and high levels of HIV/AIDS. Because we want to look specifically at the partial effect of negative rainfall shocks, our analysis is limited to the specifications in Table 1 that model rainfall using percentage positive and negative rainfall deviations from the district and national long-term averages. Table 7 presents the results of the simulations for the partial effects of negative rainfall shocks evaluated at mean and high levels of HIV/AIDS.

For both the mean household value of crop output and output per hectare, the partial effect of a large negative rainfall shock in the contemporaneous models is 'more negative' when HIV/AIDS is high than when HIV/AIDS is at its mean level. When lags of HIV prevalence or the AIDS-related mortality rate are introduced into the model, some of the partial effects continue to follow this pattern but others are not statistically different from zero. In models where we find evidence that HIV/AIDS may exacerbate the negative effect of negative rainfall shocks, the mean partial effect of the negative rainfall shock on household value of crop output evaluated at mean HIV/AIDS is -15.61 (indicating a 1.20% decrease in mean household value of crop output); when evaluated at high HIV, the mean partial effect is -22.59 (-1.73%). This corresponds to an increase in the magnitude of the partial effect of the negative rainfall shock of approximately 44.7%. For mean household crop output per hectare, in models where we find evidence that HIV/AIDS may exacerbate the negative effect of negative rainfall shocks, the mean partial effect of the negative rainfall shock evaluated at mean HIV/AIDS is -12.62 (-1.24%); when evaluated at high HIV, the mean partial effect is -18.79 (-1.85%). This corresponds to an increase in the magnitude of the partial effect of the negative rainfall shock of approximately 48.9%.

The results for the partial effect of a large negative rainfall shock on mean household cultivated area are more ambiguous. *A priori*, we would not expect a significant impact of drought on area cultivated because planting decisions are made well before smallholders know what the rainfall for the growing season will be. In the contemporaneous models using district rainfall deviations and HIV prevalence, results suggest that the partial effect of a negative rainfall shock may be somewhat more negative in high HIV prevalence areas. This result does not hold in the models using national rainfall deviations, nor does it hold when we use the AIDS-related mortality rate. In some models, results suggest that a large negative rainfall shock has a positive and significant partial effect which may be 'more positive' at high levels of HIV/AIDS.

Overall, we find some evidence that HIV/AIDS may indeed exacerbate the negative effects of drought on mean household value of crop output and output per hectare – a finding that supports the NVF hypothesis.

Table 7. Partial effects of high negative rainfall shocks evaluated at mean and high HIV/AIDS

Agricultural production outcome	HIV/AIDS measure	Rainfall deviation from ____ long-term mean	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
Output (‘000 ZKw)	HIV	District	t only	-12.961***	-17.618***	-11.574***	-14.851***
			† A t-3	52.220	109.800		
			A t-7	-9.835	-19.033		
		Natl.	t only	-18.014***	-23.996***	-15.142***	-21.210***
			† D t-5	2.650	-29.745***		
			A t-5	14.749	30.663		
			A t-7	-17.635***	-26.913***		
	AIDS	District	t only	-11.903***	-15.390***	-10.692***	-12.955**
			† D t-5	12.534	4.043	10.123	20.488
			A t-5	6.635	31.025	-8.125	-9.785
			A t-7	-11.229	-15.976	-13.498	-25.564
		Natl.	t only	-16.641***	-22.719***	-15.528***	-22.142***
			† D t-7	-37.751**	-24.665		
			A t-7	-16.522***	-21.768*	-14.088***	-17.638
Output/ha (‘000 ZKw/ha)	HIV	District	t only	-8.587***	-13.095***	-7.978***	-12.431***
			† A t-3	-128.977	-257.835		
			A t-7	-9.035*	-20.382***		
		Natl.	t only	-13.899***	-17.189***	-12.696***	-16.409***
			† A t-3	-107.869	-209.817		
			A t-7	-20.047***	-32.404***		
	AIDS	District	t only	-7.853***	-11.033***	-6.962***	-10.321***
			† D t-7	12.081	-12.497	10.015	-4.503
			A t-7	-3.310	0.0141	-4.478	-4.364
		Natl.	t only	-13.459***	-17.699***	-12.916***	-17.498***
			† D t-7	-4.953	9.229		
			A t-7	-15.429***	-19.691***	-14.212***	-17.980**
Area (ha)	HIV	District	t only	-0.005***	-0.011***	-0.004***	-0.009***
			A t-6	0.0128	0.0204		
			† A t-7	0.0023	0.0006		
		Natl.	t only	0.074	0.000	0.002	0.002
			† D t-5	0.0170***	0.0094		
			A t-5	0.0544***	0.103***		
			A t-7	0.0144***	0.0288***		
	AIDS	District	t only	-0.005***	-0.012***	-0.004**	-0.012***
			† A t-3	0.274*	0.721*	0.263*	0.692*
			A t-7	-0.0004	0.0000	-0.0014	-0.0051
		Natl.	t only	0.002	0.001	0.002	0.001
			† A t-3	0.116	0.299	0.150	0.385
			A t-7	0.0099***	0.0210**	0.0122***	0.0248***

Source: Authors’ calculations

Notes: Partial effect of a one percentage point increase in the high negative rainfall shock on mean household agricultural production outcomes. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. ‘Mean HIV/AIDS’ means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; ‘high HIV/AIDS’ partial effects were evaluated at the 90th percentile. † indicates the ‘preferred’ lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant.

4.3.2. Evidence that HIV/AIDS exacerbates the effects of other shocks?

In much of the literature on the NVF hypothesis, de Waal suggests that HIV/AIDS may be exacerbating the effects of other shocks in addition to drought. To test this hypothesis, we consider ‘other shocks’ such as high positive rainfall shocks (corresponding to floods), changes in fertilizer subsidies and agricultural sector spending associated with structural adjustment reforms, and gender inequality embodied in the effect of female household headship on agricultural production outcomes.

4.3.2.a. HIV/AIDS and positive rainfall shocks

The results of the simulations of the partial effect of large positive rainfall shocks on agricultural livelihood indicators at mean and high levels of HIV/AIDS are presented in Table 8 below.

Table 8. Partial effects of high positive rainfall shocks evaluated at mean and high HIV/AIDS

Agricultural production outcome	HIV/AIDS measure	Rainfall deviation from ____ long-term mean	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
Output (‘000 ZKw)	HIV	District	t only	1.610	1.297	-0.095	-1.322
			† A t-3	244.766**[20]	493.098**		
			A t-7	10.181**	19.907**		
		Natl.	t only	-2.829	-1.737	-3.807*	-4.856
			† D t-5	-5.730	-11.065		
			A t-5	-19.475	-31.293		
			A t-7	-13.100**	-18.542		
	AIDS	District	t only	-0.118	-3.122	-0.927	-2.452
			† D t-5	0.784	29.154	0.637	32.102
			A t-5	21.975	57.465	15.528	42.209
			A t-7	6.860	11.103	4.533	7.664
		Natl.	t only	-3.100	3.873	-3.566*	2.179
			† D t-7	-50.385**	-40.170		
			A t-7	4.568	31.351	7.373	37.300
Output/ha (‘000 ZKw/ha)	HIV	District	t only	0.6439	0.434	-0.209	-0.366
			† A t-3	-3.607	-6.644		
			A t-7	-2.818	-1.750		
		Natl.	t only	-3.715***	-4.098	-3.922***	-4.712
			† A t-3	-171.518	-337.408	-222.841*	-44.634*
			A t-7	-5.266	-3.214		
	AIDS	District	t only	0.340	-1.186	-0.316	-1.367
			† D t-7	1.969	8.986	2.119	12.380
			A t-7	7.616*	20.572*	5.372	16.030
		Natl.	t only	-2.944	-3.148	0.530	-0.127
			† D t-7	-77.050***	-87.138***		
			A t-7	-8.071	-11.015	-7.114	-9.084
Area (ha)	HIV	District	t only	0.001	0.001	0.001	0.002
			A t-6	0.0185***	0.0325***		
			† A t-7	0.00943***	0.0139***		
		Natl.	t only	0.000	-0.003	-0.000	-0.004
			† D t-5	-0.00410	-0.00992		
			A t-5	0.0300	0.0620		
			A t-7	0.000450	0.00268		
	AIDS	District	t only	0.001	-0.002	0.000	-0.002
			† A t-3	-0.0282	-0.0685	-0.0225	-0.0528
			A t-7	0.00228	-0.00532	0.00254	-0.00334
		Natl.	t only	0.002	0.006	0.001	0.006
			† A t-3	0.249**	0.646**	0.239**	0.620**
			A t-7	0.0141**	0.0447**	0.0164***	0.0495***

Source: Authors’ calculations

Notes: Partial effect of a one percentage point increase in the high positive rainfall shock on mean household agricultural production outcomes. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive

[20] The partial effects results for high positive rainfall shocks in several of the “A t-3” models are unreasonably large in magnitude. Three years is the lowest number of lags that can be used in an Almon lag so the large magnitude of the results for some of these models may be due to high collinearity among the Almon lag variables. (The confidence intervals are also very large.)

and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant.

We find no evidence that HIV/AIDS is exacerbating the effect of large positive rainfall shocks on mean household agricultural production outcomes. In only one case in all of the models for the three dependent variables do we find a negative partial effect of the large positive rainfall shock to be 'more negative' when evaluated at high HIV/AIDS levels as compared to mean HIV/AIDS. In all other cases, the effect is either not statistically different from zero or the partial effect is positive at mean HIV/AIDS and 'more positive' at high HIV/AIDS.

4.3.2.b. HIV/AIDS and fertilizer subsidies

The results of the simulations of the partial effect of fertilizer subsidy shocks on agricultural livelihood indicators at mean and high levels of HIV/AIDS are presented in Table 9 below.

Table 9. Partial effects of fertilizer subsidy shocks evaluated at mean and high HIV/AIDS

Agricultural production outcome	HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
Output ('000 ZKw)	HIV	Annual	t only	3.134***	2.717***	3.152***	2.826***
			D t-1	3.516***	3.228***		
			† A t-7	3.023***	0.331	2.977***	0.287
		Dist. dev.	t only	3.365***	2.205***	3.394***	2.454***
			† A t-3	4.111***	3.164**		
			A t-7	3.627***	2.058		
		Natl. dev.	t only	3.095**	2.600**	3.070***	2.728**
			† D t-5	3.898***	1.153		
			A t-5	3.262***	-0.141		
			A t-7	2.638***	-0.458		
	AIDS	Annual	t only	3.217***	3.224***	3.023***	2.921***
			D t-1	1.875**	0.613		
			†A t-7	2.076***	0.312	2.125***	0.617
		Dist dev.	t only	2.705***	2.783***	2.248*	2.361**
			† D t-5	1.798**	9.965	1.510*	8.565
			A t-5	3.294***	1.431	2.986***	1.418
			A t-7	3.030**	1.920	3.039***	2.409
		Natl. dev.	t only	2.929***	2.938***	2.753***	2.776***
			† D t-7	3.227***	11.190*		
			A t-7	2.085***	0.637	2.189***	1.086
Output/ha ('000 ZKw/ha)	HIV	Annual	t only	1.037***	1.358***	0.966***	1.321**
			† A t-4	1.830***	2.888***	1.810***	2.933***
			A t-7	1.946***	2.384**		
		Dist. dev.	t only	1.057***	1.413***	1.020***	1.390***
			† A t-3	2.506***	3.295***		
			A t-7	2.065***	3.802***		
		Natl. dev.	t only	0.965***	1.284***	0.942**	1.252***
			† A t-3	2.030***	3.220***	1.968***	2.960***
			A t-7	1.720***	2.860***		
	AIDS	Annual	t only	1.136***	2.133***	1.034***	2.106***
			D t-1	1.398***	2.330***		
			†A t-7	1.459***	3.170**	1.439**	3.365***
		Dist. dev.	t only	2.470***	2.308***	2.525***	2.351***
			† D t-7	1.758**	9.923**	1.676**	9.425*
			A t-7	1.668***	3.264**	1.642***	3.311**
		Natl. dev.	t only	1.996***	1.859***	2.006***	1.865***

			† D t-7	2.463***	13.737***		
			A t-7	1.605***	3.819***	1.623***	4.027***
Area (ha)	HIV	Annual	t only	0.001***	0.000	0.001**	0.000
			† A t-4	-0.0004	-0.0020*		
			A t-7	-0.0006	-0.0024**		
		Dist. dev.	t only	0.001***	0.000	0.001***	0.000
			A t-6	0.0003	-0.0007		
			† A t-7	0.0094***	0.0139***		
		Natl. dev.	t only	0.001***	0.000	0.001***	0.000
			† D t-5	0.0005	-0.0020*		
			A t-5	-0.0001	-0.0019*		
			A t-7	-0.0002	-0.0018*		
	AIDS	Annual	t only	0.001***	0.001	0.001***	0.001
			† D t-1	-0.0007	-0.0023**		
			A t-7	-0.0001	-0.0022*	-0.0001	-0.0019
		Dist. dev.	t only	0.001	0.001	0.001	0.001
			† A t-3	0.0002	-0.0019*	0.0002	-0.0017
			A t-7	0.0005	-0.0013	0.0004	-0.0011
		Natl. dev.	t only	0.001	0.001	0.000	0.000
			† A t-3	-0.0011**	-0.0035**	-0.0011**	-0.0031**
			A t-7	0.0001	-0.0017	0.0001	-0.0012

Source: Authors' calculations

Notes: Partial effect of a one kilogram/hectare increase in the mean household fertilizer subsidy on mean household agricultural production outcomes. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant.

The partial effect of an increase in the mean household fertilizer subsidy on the value of crop output is 'less positive' when evaluated at high HIV prevalence levels. However, when we use the AIDS-related mortality rate instead of HIV prevalence, the partial effect is 'more positive' in some models but 'less positive' in others. The partial effect of an increase in fertilizer subsidies on the value of output per hectare is consistently 'more positive' when evaluated at high HIV/AIDS relative to mean HIV/AIDS. The partial effect of an increase in fertilizer subsidies on mean household cultivated area is quite sensitive to model specification and this effect is small in magnitude (less than 1%) in all models. However, this partial effect is consistently 'more negative' or 'less positive' when evaluated at high HIV/AIDS relative to mean HIV/AIDS levels.

4.3.2.c. HIV/AIDS and agricultural sector budget allocations

The results of the simulations of the partial effect of agricultural budget allocation shocks on agricultural production outcomes at mean and high levels of HIV/AIDS are presented in Table 10 below.

Table 10. Partial effects of a 10% increase in the agricultural sector budget evaluated at mean and high HIV/AIDS

Agricultural production outcome	HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
Output ('000 ZKw)	HIV	Annual	t only	-6.809	-29.208***	-5.526	-20.228**
			D t-1	-16.775***	-66.211***		
			† A t-7	-4.756	-61.080***	-1.184	-52.594***
		Dist. dev.	t only	-9.275*	-33.352***	-7.401	-24.274***
			† A t-3	70.059***	112.884***		
			A t-7	-7.410	-66.408***		

		Natl. dev.	t only	-6.513	-29.208	-4.736	-22.597***
			† D t-5	31.379**	-60.389**		
			A t-5	-15.689***	-60.586***		
			A t-7	1.154	-50.226***		
	AIDS	Annual	t only	-14.801***	-57.725***	-14.900***	-57.429***
			D t-1	-22.794***	-66.704***		
			†A t-7	-17.564***	-76.967***	-15.097***	-78.151***
		Dist dev.	t only	-58.514***	-52.594***	-58.416***	-52.495***
			† D t-5	-38.089***	-109.332	-37.694***	-136.172
			A t-5	-28.616***	-98.576***	-27.530***	-104.003***
			A t-7	-15.492***	-70.553***	-15.689***	-75.684***
		Natl. dev.	t only	-53.285***	-47.561***	-54.074***	-48.252***
			† D t-7	-109.036***	-239.287***		
			A t-7	-10.262*	-64.040***	-8.604	-66.902***
Output/ha ('000 ZKw/ha)	HIV	Annual	t only	3.552	-0.592	5.230	4.736
			† A t-4	-2.171	4.144		
			A t-7	10.065***	-6.118	12.038***	-3.552
		Dist. dev.	t only	2.171	-4.736	4.835	3.256
			† A t-3	12.828	17.465		
			A t-7	5.822	-11.446		
		Natl. dev.	t only	4.638	1.381	5.921	5.131
			† A t-3	25.656**	49.338**	24.471***	47.265***
			A t-7	10.262**	2.368		
	AIDS	Annual	t only	1.875	-2.072	2.072	-3.355
			D t-1	-2.052	-10.756		
			†A t-7	6.453	-5.703	7.628*	-9.423
		Dist. dev.	t only	-8.387	-7.302	-9.275	-7.993
			† D t-7	-39.075*	-299.972***	-42.036**	-306.386***
			A t-7	3.690	-6.295	4.549	-9.394
		Natl. dev.	t only	4.046	4.046	3.059	3.158
			† D t-7	-56.541***	-296.518***		
			A t-7	7.272*	-2.674	8.338***	-6.424
Area (ha)	HIV	Annual	t only	-.0178***	-.0350***	-.0169***	-.0321***
			† A t-4	-.0205***	-.0655***		
			A t-7	-.0208***	-.0935***		
		Dist. dev.	t only	-.0157***	-.0301***	-.0150***	-.0282***
			A t-6	-.0154***	-.0595***		
			† A t-7	-.0128***	-.0541***		
		Natl. dev.	t only	-.0177***	-.0349***	-.0165***	-.0317***
			† D t-5	-.0286***	-.0444***		
			A t-5	-.0207***	-.0858***		
			A t-7	-.0187***	-.0760***		
	AIDS	Annual	t only	-.0218***	-.0587***	-.0216***	-.0590***
			† D t-1	-.0217***	-.0474***		
			A t-7	-.0296***	-.0770***	-.0296***	-.0799***
		Dist. dev.	t only	-.0472***	-.0433***	-.0482***	-.0442***
			† A t-3	-.0323***	-.0819***	-.0323***	-.0750***
			A t-7	-.0176***	-.0543***	-.0187***	-.0592***
		Natl. dev.	t only	-.0594***	-.0541***	-.0604***	-.0549***
			† A t-3	.0128	.0355	.0148	.0326
			A t-7	-.0296***	-.0770***	-.0276***	-.0799***

Source: Authors' calculations

Notes: Partial effect of a 10% increase in the agricultural sector budget on mean household agricultural production outcomes. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant.

In the cases of mean household value of crop output and mean household cultivated area, we find evidence that the negative partial effect of a 10% increase in agricultural sector budgets is 'more negative' at high levels of HIV/AIDS relative to mean levels of the epidemic. There is no clear pattern in the relative magnitude of the partial effect of agricultural sector budgets on mean household value of crop output per hectare and in the majority of models, the partial effect is not statistically different from zero.

In models where we find evidence that HIV/AIDS may exacerbate the negative effect of an increase in the agricultural sector budget, the mean partial effect of a 10% increase in the agricultural sector budget on household value of crop output evaluated at mean HIV/AIDS is -12.59 (indicating a 0.97% decrease in mean household value of crop output); when evaluated at high HIV, the mean partial effect is -66.80 (-5.12%). This corresponds to a four-fold increase in the magnitude of the partial effect of the agricultural sector budget shock. For mean household cultivated area, in models where we find evidence that HIV/AIDS may exacerbate the negative effect of an increase in the agricultural sector budget, the mean partial effect of the agricultural budget shock evaluated at mean HIV/AIDS is -0.02 (-1.61%); when evaluated at high HIV, the mean partial effect is -0.06 (-4.75%). This also corresponds to a four-fold increase in the magnitude of the partial effect of the agricultural sector budget shock.

The findings of a negative partial effect of increases in the agricultural sector budget on mean household value of crop output and cultivated area and of this effect being exacerbated by HIV/AIDS are difficult to interpret. Agricultural sector budget figures broken down by category were not available for the entire period of analysis so the agricultural sector budget variable used in the analysis is a composite measure of budget allocations for fertilizer subsidies, Food Reserve Agency (FRA) maize marketing operations, poverty reduction/HIPC[21] programs, etc.[22] For this reason, we are unable to discern which aspects of agricultural sector spending are having positive versus negative partial effects on rural farm production.

4.3.2.d. HIV/AIDS and female household headship

The results of the simulations of the partial effect of female household-headship shocks on agricultural production outcomes at mean and high levels of HIV/AIDS are presented in Table 11 below.

Table 11. Partial effects of female headship shocks evaluated at mean and high HIV/AIDS

Agricultural production outcome	HIV/AIDS measure	Rainfall measure	Lag structure	Evaluated at mean HIV/AIDS	Evaluated at high HIV/AIDS	Evaluated at mean HIV/AIDS (with time trend)	Evaluated at high HIV/AIDS (with time trend)
Output ('000 ZKw)	HIV	Annual	t only	-3.055	-8.633**	-2.113	-6.457
			D t-1	-2.074	-8.925**		
			† A t-7	-3.490	-10.242**	-3.878*	-11.067***
		Dist. dev.	t only	-0.447	-7.696*	-0.305	-7.452*
			† A t-3	0.395	-5.334		
			A t-7	-2.206	-13.113**		
		Natl. dev.	t only	-1.945	-8.050**	-1.332	-6.200
			† D t-5	-2.471	-11.420**		
			A t-5	-2.559	-9.775**		
			A t-7	-4.408**	-10.907***		
	AIDS	Annual	t only	-2.751	-11.135***	-2.436	-10.242**
			D t-1	-2.532	-5.185		
			†A t-7	-2.660	-7.568*	-3.124	-6.958*
		Dist dev.	t only	-11.130**	-9.741**	-8.851*	-7.703*
			† D t-5	-0.177	-18.535	-0.029	-20.387
			A t-5	-1.534	-9.476*	-1.517	-9.325*
			A t-7	-1.911	-10.214**	-2.056	-10.162**
		Natl. dev.	t only	-13.566***	-11.977***	-11.748***	-10.363***
			† D t-7	-6.898	2.234		
			A t-7	-2.749	-10.800***	-3.348	-10.530**

[21] Highly Indebted Poor Countries.

[22] See Govereh et al., 2006 for details on public investment in the agricultural sector in Zambia.

Output/ha ('000 ZKw/ha)	HIV	Annual	t only	-1.176	-5.413**	-0.877	-4.735*
			† A t-4	-1.139	-1.670		
			A t-7	-1.586	-4.001	-1.553	-3.209
		Dist. dev.	t only	0.346	-3.535	0.513	-3.093
			† A t-3	1.140	-2.621		
			A t-7	-1.378	-5.382*		
		Natl. dev.	t only	-0.343	-4.684*	-0.356	-4.519*
			† A t-3	-0.094	-0.958	-0.073	-0.895
			A t-7	-2.012	-3.341		
	AIDS	Annual	t only	-0.801	-5.084	-0.395	-4.107
			D t-1	-0.545	-3.889		
			†A t-7	-1.000	-1.729	-1.196	-0.733
		Dist. dev.	t only	-4.897	-4.163	-4.130	-3.443
			† D t-7	4.706	-3.003	5.549	-0.001
			A t-7	-0.357	-3.336	0.058	-2.128
		Natl. dev.	t only	-4.195	-3.632	-3.706	-3.183
			† D t-7	6.087**	16.744		
			A t-7	-0.9444	-2.061	-1.176	-1.373
Area (ha)	HIV	Annual	t only	-0.004*	-0.007**	-0.003**	-0.006**
			† A t-4	-0.005***	-0.011***		
			A t-7	-0.006***	-0.011***		
		Dist. dev.	t only	-0.004***	-0.009***	-0.004**	-0.009***
			A t-6	-0.004**	-0.011***		
			† A t-7	-0.006***	-0.012***		
		Natl. dev.	t only	-0.004**	-0.007**	-0.003**	-0.006**
			† D t-5	-0.005**	-0.010***		
			A t-5	-0.004***	-0.010***		
			A t-7	-0.007***	-0.012***		
	AIDS	Annual	t only	-0.004***	-0.007***	-0.004***	-0.006*
			† D t-1	-0.005***	-0.007**		
			A t-7	-0.005***	-0.011***	-0.005***	-0.010***
		Dist. dev.	t only	-0.009**	-0.008**	-0.009**	-0.008**
			† A t-3	-0.004**	-0.003	-0.004**	-0.003
			A t-7	-0.005***	-0.013***	-0.005***	-0.013***
		Natl. dev.	t only	-0.008**	-0.007**	-0.007**	-0.007**
			† A t-3	-0.005***	-0.006	-0.005***	-0.006
			A t-7	-0.005***	-0.011***	-0.005***	-0.010***

Source: Authors' calculations

Notes: Partial effect of a one percentage point increase in the percentage of female-headed households in a district on mean household agricultural production outcomes. HIV = HIV prevalence rate; AIDS = AIDS-related mortality rate; Annual = mean annual rainfall; Dist. dev. = percentage positive and negative deviations from long-term district average rainfall; Natl. dev. = percentage positive and negative deviations from long-term national average rainfall; D t-j = finite distributed lag with maximum lag length of j years; A t-j = Almon lag with maximum lag length of j years; t only = Contemporaneous only. 'Mean HIV/AIDS' means the partial derivative of crop output with respect to HIV/AIDS was evaluated at the mean value of HIV prevalence or AIDS-related mortality rate; 'high HIV/AIDS' partial effects were evaluated at the 90th percentile. † indicates the 'preferred' lag structure. * significant at 10%; ** significant at 5%; *** significant at 1%. Results are only reported for models including the time trend in cases where the partial effect of the time trend was statistically significant.

The partial effect of an increase in the percentage of female-headed households in a district on mean household value of crop output appears to be exacerbated by HIV/AIDS. While this partial effect evaluated at mean HIV/AIDS is, in most cases, not statistically different from zero, the partial effect evaluated at high HIV/AIDS is negative and significant ($p<0.10$), with an average decline in crop output of 0.7% (-97,000 ZKw). This finding is consistent across all model specifications except those using the contemporaneous AIDS-related mortality rate and rainfall deviations from district or national averages.

An increase in the percentage of female-headed households in a district has little impact on mean household value of crop output per hectare, as this partial effect is rarely statistically different from zero. In the case of mean household cultivated area, an increase in female-headed households consistently has a negative and significant ($p<0.05$) partial effect. When this partial effect is evaluated using HIV prevalence, the effect is 'more negative' at high HIV prevalence (-0.67% on average) than at mean HIV prevalence (-0.37% on average). This corresponds to an 80% increase in the magnitude of the negative shock; however, in absolute terms, the negative impact of the shock at both mean and high HIV prevalence is quite small (less than 0.1%). The simulation results from the models using the AIDS-related mortality rate instead of HIV prevalence are more ambiguous, with the negative partial effect of female headship being 'more negative' in some models when evaluated at a high AIDS-related mortality rate, and 'less negative' in others.

4.3.3. Summary of indirect effect of HIV/AIDS on agricultural production outcomes

Table 12 summarizes the results of the indirect effects of HIV/AIDS on agricultural production outcomes as described above.

Table 12. Summary of the indirect effects of HIV/AIDS on agricultural production outcomes

Shock	HIV/AIDS measure	Partial effect of an increase in the shock on ______ evaluated at high HIV/AIDS relative to mean levels		
		Crop output	Crop output/ha	Cultivated area
Large negative rainfall deviation	HIV prevalence	*More neg.	*More neg.	Ambiguous
	AIDS mortality	*More neg.	*More neg.	Ambiguous
Large positive rainfall deviation	HIV prevalence	--	--	--
	AIDS mortality	--	--	--
Fertilizer subsidy changes	HIV prevalence	*Less pos.	More pos.	*Less pos./More neg.
	AIDS mortality	Ambiguous	More pos.	*Less pos./More neg.
Agricultural sector budget changes	HIV prevalence	*More neg.	--	*More neg.
	AIDS mortality	*More neg.	--	*More neg.
% of female-headed households	HIV prevalence	*More neg.	--	*More neg.
	AIDS mortality	*More neg.	--	Ambiguous

Source: Authors' calculations

Notes: * indicates results that are consistent with the predictions of the NVF hypothesis, i.e., that HIV/AIDS exacerbates the impacts of shocks on agricultural production outcomes. 'More neg.' = in most models, the partial effect of the shock is more negative when at evaluated at high HIV/AIDS levels compared to mean HIV/AIDS levels; 'More pos.' = this partial effect is more positive; 'Less pos.' = this partial effect is less positive. 'Ambiguous' = the findings are inconclusive. -- = the partial effects are not statistically different from zero in the vast majority of model specifications.

For drought, agricultural sector budget decreases, and gender inequality shocks, the results for two or more of the agricultural production outcomes considered are consistent with the NVF hypothesis prediction that the impacts of such shocks are exacerbated by HIV/AIDS. In the case of large positive rainfall shocks, the partial effects of such shocks on agricultural production outcomes are not statistically different from zero. And in the case of fertilizer subsidy changes related to structural adjustment, the partial effect of such a shock on mean household value of crop output and cultivated area appears to be exacerbated by HIV/AIDS while the partial effect on mean household value of crop output per hectare appears to be mitigated when HIV prevalence or AIDS-related mortality is high.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The new variant famine hypothesis has become an important framework for understanding the impacts of HIV/AIDS on rural livelihoods. This paper is the first to set out to empirically test its predictions. Using nationally-representative panel data from 1991 to 2003, we use descriptive and econometric analysis to examine three main questions with the goal of 'testing' the NVF hypothesis in Zambia: (1) Is rural farm production in Zambia declining over the period 1991-2003? (2) Is HIV/AIDS having a negative direct effect on agricultural production outcomes? And (3) Is HIV/AIDS indirectly affecting agricultural production outcomes by exacerbating the impacts of drought and other shocks? The analysis generates a number of findings that may help evaluate the validity of the new variant famine hypothesis as an analytical framework in the context of rural livelihoods and food security in Zambia.

First, we find little evidence of a systematic decline in rural livelihoods at the national or provincial level as measured by mean household value of crop output, crop output per hectare, and cultivated area. The values of these agricultural production outcomes vary considerably over the period 1991-2003, with fluctuations in crop production correlated with rainfall levels. The patterns are heterogeneous at the provincial level, with agricultural production outcomes declining in some provinces or remaining steady or rising in others.

Second, the estimated partial effect of HIV/AIDS on rural farm production indicators is quite sensitive to model specification: contrary to the *a priori* prediction, we do not find a robust negative partial effect of HIV/AIDS on any of the three mean household agricultural production outcomes considered when evaluated at mean or high HIV/AIDS levels. We present a number of potential explanations for this counterintuitive finding in section 4 above.

Third, although we do not find consistent evidence of a negative *direct* effect of HIV/AIDS on rural farm production, we do find some evidence that HIV/AIDS may have negative *indirect* effects on agricultural production outcomes by exacerbating the impacts of disturbances such as large negative rainfall shocks, gender inequalities and agricultural sector policy changes related to structural adjustment. These indirect effects vary across agricultural production outcomes but the results are generally consistent with the predictions of the new variant famine hypothesis. The negative effects of drought on total and per hectare value of crop production are more negative in magnitude when HIV prevalence or AIDS-related mortality is relatively high. The positive impacts of fertilizer subsidies on total value of crop production and cultivated area are less positive in magnitude at high HIV prevalence. We find some evidence that gender inequalities, which result in female-headed households producing lower values of crop output or cultivating less area, are also worsened by HIV/AIDS.

The NVF hypothesis prediction that the effects of exogenous shocks on rural households are exacerbated by the generalized HIV/AIDS epidemic is indeed supported by nationally-representative survey results from Zambia. Efforts to target assistance toward communities that are drought-prone or have large numbers of female-headed households and are also highly AIDS-affected may be an important aspect of food security and HIV/AIDS mitigation programs and policies. The finding of little evidence of declines in rural farm production due to the direct effects of HIV/AIDS or in general over time suggests that, on average, smallholder households may be more resilient in the face of HIV/AIDS than predicted. Therefore, it will be important for governments, donors and NGOs to continue to invest in AIDS mitigation and rural development, broadly defined, to bolster resilient livelihood strategies.

This paper is an important step toward establishing a stronger understanding of the interactions between HIV/AIDS, the agricultural sector, and rural livelihoods. The results raise several interesting questions that we plan to investigate further. *First*, the econometric analysis in this paper involves estimating one set of results for Zambia as a whole, pooling districts from different agroecological zones. Given the importance of rainfall in affecting agricultural production outcomes in Zambia, it is quite possible that the estimates of the direct and indirect effects of HIV/AIDS may differ by agroecological zone. Thus, we plan to test if such a disaggregated analysis is appropriate. *Second*, the current analysis also considers mean agricultural production outcomes based on data from both male- and female-headed households. Given the important gender dimensions of HIV/AIDS, it is possible that HIV/ADS is having differential impacts on smallholder agricultural production depending on the sex of the household head. We will test to see if it is appropriate to estimate separate models by gender of the head of household. *Third*, given that the estimation results from several models suggest a counter-intuitive positive partial effect of HIV/AIDS on rural farm production, we plan to test for threshold effects in the impacts of HIV/AIDS on agricultural production outcomes and to estimate quantile regression models to determine if the impacts of AIDS differ across different percentiles of these agricultural production outcomes.

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APPENDIX

Table A1. Summary statistics for explanatory variables

Variable	Obs.	Years*	Mean	Std. Dev.	Min	Max	10th percentile	90th percentile
HIV	624	1991-2002	11.920	7.258	1.529	34.513	4.305	21.323
AIDS	624	1991-2002	4.518	4.302	0.141	21.053	0.669	10.926
RAIN	624	1991/2-2002/3	9.500	2.268	3.600	15.988	6.556	12.500
POSD	624	1991/2-2002/3	5.511	10.360	0	70.126	0	20.091
NEGD	624	1991/2-2002/3	10.134	11.589	0	64.101	0	26.819
POSN	624	1991/2-2002/3	6.194	10.611	0	58.143	0	23.640
NEGN	624	1991/2-2002/3	12.225	15.462	0	64.392	0	35.158
PPI	572	1992/3-2002/3	12.391	5.277	4.271	48.256	7.462	19.525
FERT	624	1991-2002	2171.564	810.024	747.426	3777.145	1351.773	3489.617
IR	624	1991-2002	-3.026	24.086	-48.094	25.116	-41.790	17.640
SUB	624	1991/2-2002/3	26.128	48.699	0	594.676	0	69.833
FEM	624	1991/2-2002/3	22.750	7.584	0	55.079	13.6048	32.41497
BUD	624	1991-2002	986.750	753.701	327.000	3100.000	376	1788

Source: Authors' calculations

Notes: *1991-2002 denotes the corresponding calendar years; 1991/2-2002/3 denotes the corresponding agricultural years (e.g., 1991/2 = October 1991 through September 1992).

Where:

Variable	Description	Units	Level
HIV	Estimated HIV prevalence rate	%	District
AIDS	Estimated AIDS-related mortality rate	%	District
RAIN	Mean annual rainfall for agricultural year	'00 mm	District
POSD	Positive rainfall shock, deviation from 20-year district average	%	District
NEGD	Negative rainfall shock, deviation from 20-year district average	%	District
POSN	Positive rainfall shock, deviation from national average	%	District
NEGN	Negative rainfall shock, deviation from national average	%	District
PPI	Agricultural producer price index in year t-1	Real '00 ZKw/kg	District
FERT	Price of fertilizer	Real ZKw/kg	Provincial
IR	Real interest rate in year t-1	%	National
SUB	Fertilizer subsidy	Mean kg/ha/household	District
FEM	Percentage of female-headed households	%	District
BUD	National budget allocation to the agricultural sector	Real bil ZKw	National

Table A2. Summary statistics for dependent variables

Mean household agricultural production outcome	Units	Obs	Years	Mean	Std. Dev.	Min	Max
Cultivated area	ha	624	1991/2-2002/3	1.347	0.516	0.170	3.725
Crop output	'000 ZKw	624	1991/2-2002/3	1304.146	689.039	0.000	3976.221
Crop output per hectare	'000 ZKw/ha	624	1991/2-2002/3	1015.998	409.623	0.000	4533.394

Source: Based on raw data from PHS surveys, 1991/2-2002/3, Central Statistical Office, Lusaka.

Table A3. Correlation matrix of explanatory variables

	HIV	AIDS	RAIN	POSD	NEGD	POSN	NEGN	PPI	FERT	IR	SUB	FEM	BUD
HIV	1.00												
AIDS	0.90	1.00											
RAIN	-0.26	-0.11	1.00										
POSD	0.05	0.02	0.36	1.00									
NEGD	0.05	0.05	-0.60	-0.46	1.00								
POSN	-0.18	-0.06	0.80	0.32	-0.38	1.00							
NEGN	0.25	0.12	-0.90	-0.31	0.61	-0.46	1.00						
PPI	-0.18	-0.23	0.01	-0.12	0.03	-0.01	-0.02	1.00					
FERT	-0.18	-0.28	0.10	-0.06	-0.13	0.04	-0.11	0.48	1.00				
IR	0.23	0.29	0.14	0.13	-0.18	0.09	-0.15	-0.71	-0.34	1.00			
SUB	0.04	-0.05	-0.09	-0.07	0.05	-0.03	0.12	0.39	0.23	-0.42	1.00		
FEM	-0.22	-0.24	-0.02	0.17	-0.08	-0.06	-0.02	-0.10	0.00	0.03	-0.21	1.00	
BUD	-0.21	-0.28	-0.05	-0.02	0.12	0.04	0.11	0.60	0.56	-0.71	0.39	-0.06	1.00

Source: Authors' calculations

Table A4. Correlation between HIV prevalence and AIDS-related mortality

HIV prevalence in year	Correlation with AIDS-related mortality	AIDS-related mortality in year	Correlation with HIV prevalence
t-1	0.923	t-1	0.879
t-2	0.938	t-2	0.854
t-3	0.948	t-3	0.827
t-4	0.952	t-4	0.797
t-5	0.950	t-5	0.765
t-6	0.939	t-6	0.728
t-7	0.920	t-7	0.701

Source: Based on raw data from *Zambia: HIV/AIDS Epidemiological Projections: 1985-2010* (CSO, 2005) and Zambian population census data (CSO, 1975; CSO, 1985; CSO, 1994; CSO, 2003).