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A Test of the New Variant Famine Hypothesis: Panel Survey Evidence from Zambia

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1. INTRODUCTION

The 'new variant famine' (NVF) hypothesis, which postulates that HIV/AIDS is eroding the viability of agrarian livelihoods and making rural communities more sensitive and less resilient to drought and other shocks, has become a high profile but controversial part of the debate on HIV/AIDS and food crises (de Waal and Whiteside, 2003; de Waal and Tumushabe, 2003; de Waal, 2004; van Riet, 2007). Although NVF has begun to shape HIV/AIDS mitigation and food security related policies and programs, there is a dearth of empirical evidence to support NVF (de Waal and Tumushabe, 2003; de Waal, 2004). To date there has been no empirical study that directly tests the NVF hypothesis (de Waal, 2007).

In this study, we use econometric techniques to test two key predictions of NVF: (1) that HIV/AIDS is causing a decline in agrarian livelihoods, a key element of which is agricultural productivity; and (2) that HIV/AIDS interacts with and exacerbates the effects of drought shocks. We use nationally representative district-level panel data from Zambia (1991/2-2004/5) to estimate the impact of HIV/AIDS-related morbidity and mortality, drought, and their interactions on mean household crop output, crop output per hectare, and area planted (henceforth referred to as 'agricultural production indicators').[1]

The objectives of the paper are to: (1) understand the dynamic effects of AIDS-related morbidity and mortality on agricultural production indicators; (2) measure the extent to which HIV/AIDS may exacerbate the impacts of drought on agricultural production; and (3) determine whether these 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. Zambia is a suitable test case of the NVF hypothesis because,

[1] Other aspects of agrarian livelihoods that could be examined include consumption or expenditure, income (farm and off-farm), and nutrition-related outcomes (e.g., anthropometrics). However, the district-level panel data required for such analyses are not available for Zambia.

with an HIV prevalence rate of 15.2%, it is among the seven most-highly afflicted countries in the world (UNAIDS, 2008). Furthermore, Zambia experienced five droughts between 1991 and 2003 (Govereh and Wamulume, 2006; del Ninno and Marini, 2005).

The paper begins with a description of the methods and data used. We then describe the results of the analysis and, finally, outline the conclusions and policy implications.

2. THE MODEL

We base our test of the NVF hypothesis on a supply response framework and estimate equations to explain the area planted and yield (crop output per hectare) decisions of Zambian smallholders. The area planted and yield decisions are allowed to depend on input and output prices as well as HIV prevalence, rainfall shocks, and interaction effects between HIV/AIDS and rainfall.[2] We assume a linear in parameters functional form and normalize input and output prices by wages so that the area and yield equations are specified as:

$$\log AREA_{i,t} = \alpha + \gamma_1 \log P^{Y*}_{i,t-1} + \gamma_2 \log p^{fert*}_{k,t} + \gamma_3 \log P^{lstock*}_{k,t} + \boldsymbol{HIV}_{i,t}\boldsymbol{\delta_1} + \boldsymbol{HIV}^2_{i,t}\boldsymbol{\delta_2} + \boldsymbol{T}_t\boldsymbol{\theta} + \lambda_i + \varepsilon_{i,t} \tag{1}$$

$$\begin{aligned}\log Y^{output/ha}_{i,t} &= \alpha + \gamma_1 \log P^{Y*}_{i,t-1} + \gamma_2 \log p^{fert*}_{k,t} + \gamma_3 \log P^{lstock*}_{k,t} + \boldsymbol{HIV}_{i,t}\boldsymbol{\delta_1} + \boldsymbol{HIV}^2_{i,t}\boldsymbol{\delta_2} \\ &+ \omega_1 POS_{i,t} + \omega_2 POS^2_{i,t} + \eta_1 NEG_{i,t} + \eta_2 NEG^2_{i,t} + \boldsymbol{HIV}_{i,t} * POS_{i,t}\boldsymbol{\varphi_1} + \boldsymbol{HIV}_{it} * POS^2_{i,t}\boldsymbol{\varphi_2} \\ &+ \boldsymbol{HIV}_{i,t} * NEG_{i,t}\boldsymbol{\phi_1} + \boldsymbol{HIV}_{i,t} * NEG^2_{i,t}\boldsymbol{\phi_2} + \boldsymbol{T}_t\boldsymbol{\theta} + \lambda_i + \varepsilon_{i,t}\end{aligned} \tag{2}$$

where i indexes the district, k indexes the province, and t indexes the year; log is the natural log; $AREA$ is mean household total area planted in 17 crops; $Y^{output/ha}$ is an index of mean household crop output/ha across these 17 crops; $P^{Y*}_{i,t-1}$ is the normalized crop output price index (lagged price is used as a proxy for expected price); p^{fert*} is the normalized fertilizer price; $P^{lstock*}$ is the normalized

[2] We do not include rainfall or test for rainfall-HIV interaction effects in the area planted model because our rainfall variable, which measures rainfall over the entire growing season, is not known until after planting decisions are made.

livestock price index, which is included to control for the returns to another use to which smallholders might put their land; ***HIV*** is a vector of current and lagged estimated HIV prevalence rates; *POS* and *NEG* are positive and negative rainfall shocks, respectively; ***T*** is a vector of year dummies intended to capture the effects on agricultural production of unobserved factors that change over time, such as policy, infrastructure, and agricultural technology; λ_i is the time invariant district-level unobserved effects; and $\varepsilon_{i,t}$ is the idiosyncratic error term.[3] The squared terms for the ***HIV***, *POS*, and *NEG* variables are included to allow for the possibility of non-linear supply responses to HIV/AIDS and rainfall.

We also use the estimated area planted and yield equations to define a third production measure – an index of mean household crop output ($Y_{i,t}^{output}$), where $Y_{i,t}^{output} = Y_{i,t}^{output/ha} \times AREA_{i,t}$. Because this is a deterministic relationship, we use the estimated area and yield equations to identify effects on crop output, rather than estimating a (redundant) third equation for output.

We test the null hypotheses that HIV/AIDS has no effect on the three agricultural production indicators (area planted, crop output per hectare, and crop output) and that HIV/AIDS has no impact on the effects of rainfall shocks (i.e., that the interaction effects are zero). Statistical properties of the model are described in section 4 on estimation.

3. DATA & VARIABLE CONSTRUCTION

The definition and data source of each variable in the model are described below (see Table 1 for summary statistics).

[3] The key inferences of the paper are robust to the choice of price by which to normalize.

3.1. Agricultural production indicators

The data used to construct the agricultural production indicators (district-level mean crop output, output per hectare, and planted area per household) are from the Zambia Post-Harvest Surveys (PHS) for agricultural years 1991/2 to 2004/2005, the most recent year for which PHS data are available. The PHS is a nationally representative longitudinal survey of smallholder agriculture in 51 districts. [4] Approximately 7,000 smallholder agricultural households are included in the PHS each year, but the specific households interviewed are not the same from year to year. The data can therefore be considered a panel over 14 years, in which the cross-sectional unit of observation is the district (not the household). The dataset contains 714 observations (51 districts, 14 years). (For details on PHS sampling procedures and survey design, see Megill (2004).)

Area planted (*AREA*) is the mean household total area planted in 17 crops included in the PHS. [5] We use the Törnqvist discrete approximation to the Divisia quantity index to aggregate over these 17 crops and construct the mean household crop output variable (Y^{output}) for each district and year.

3.2. Output price indexes (P^{Y} and *P^{lstock})*

The Törnqvist discrete approximation to the Divisia price index is used to aggregate the prices for the 17 crops included in the PHS and compute a crop output price index ($P^{Y}_{i,t}$).[6] $P^{lstock}_{k,t}$ is a Divisia livestock price index for each province and year. The livestock prices included in the index are cattle, pigs, goats and sheep. Zambia PHS data are used to construct both of these price indexes.

[4] Smallholder agricultural households are defined as households that cultivate fewer than 20 hectares and produce crops, raise livestock or poultry, or farm fish. Since the 2000 census, the nine provinces of Zambia have been divided into 72 districts but at the time of the 1990 census, the country was divided into 57 districts. PHS data for six of these districts are not complete for the period 1991/2-2004/5 so we use the 51 "old" districts for which the data are complete.

[5] These 17 crops are: maize, sorghum, rice, millet, sunflower, groundnuts, soybeans, seed cotton, Irish potatoes, Virginia tobacco, burley tobacco, mixed beans, cowpeas, velvet beans, coffee, sweet potatoes, and cassava. The PHS did not regularly collect information on horticultural products, which have taken on increased importance in Zambia in recent years.

[6] Ideally, the prices of other competing crops such as horticultural crops would also be included in the output price index; however, these data are not available.

3.3. Input prices

Median provincial fertilizer prices (p^{fert}) (Zambian Kwacha per kilogram, ZMK/kg) are from the Zambian Ministry of Agriculture and Cooperatives Agricultural Marketing Information Centre. Private sector wages (mean ZMK/month) are used as a proxy for agricultural wages and are derived from a quarterly wage series obtained from the Zambia Central Statistical Office. Data on agricultural wages are missing in many years but available data suggest that agricultural and private sector wages are highly correlated (ρ=0.91).[7]

3.4. Rainfall shocks (POS and NEG)

Mean seasonal rainfall data (in millimeters) for each district are from 36 rainfall stations throughout Zambia. The positive and negative rainfall shock variables are computed as the percentage positive and negative deviations from the 16-year average district rainfall level following the procedure used by Hoddinott (2006).

*3.5. HIV prevalence rates (**HIV**)*

We use the district estimated HIV prevalence rate to model the severity of the HIV/AIDS epidemic in a given district and year. These data are from the report, *Zambia HIV/AIDS Epidemiological Projections, 1985-2010* (CSO, 2005). We model the immediate and delayed impacts of the epidemic by including both contemporaneous and lagged values of HIV prevalence in our model. To address the issue of multicollinearity created by including numerous lags of HIV prevalence, we impose a quadratic Almon lag structure, i.e., we assume in $\sum_{j=0}^{J} \alpha_j HIV_{i,t-j}$ that α_j can be approximated by $\alpha_j = a_o + a_1 j + a_2 j^2$, where $HIV_{i,t}$ is the HIV prevalence rate in district i in year t, j is the length of the lag, and J is chosen to minimize the Akaike Information Criteria (AIC) (per Pindyck and Rubinfeld, 1997; and Gujarati, 2003).

[7] Other input prices of potential relevance include the prices of seed and pesticides as well as draft animal and equipment rental rates; however, these data are not available.

4. ESTIMATION

We estimate Eqs. (1) and (2) for Zambia overall (51 districts), for low and high rainfall strata, and for low and high land-to-labor ratio strata (10 models total). [8] Table 2 summarizes the AIC-minimizing lag structure for each model and the number of districts in each stratum. We allow for the unobserved time invariant district-level heterogeneity (λ_i) in these models to be correlated with the explanatory variables, so in order to consistently estimate the models' parameters, we need to control for these unobserved effects. To do so, we use the fixed effects (FE) estimator. We find evidence of heteroskedasticity and serial correlation in the residuals of the models and therefore compute heteroskedasticity- and serial correlation-robust standard errors using the robust variance matrix estimator described in Wooldridge (2002, p. 275).

5. RESULTS

The regression results are not provided to conserve space but the interaction terms between HIV prevalence and the rainfall shocks in Eq. (2) are jointly significant at the 1% level in all models. What is important for testing the NVF prediction that HIV/AIDS exacerbates the effects of drought is to determine the *change* in the impact of a negative rainfall shock on agricultural production when the HIV prevalence rate increases. This is addressed by taking the derivative of Eq. (2) with respect to *NEG*, and then with respect to ***HIV*** to get:

$$\frac{\partial^2 \log Y_{i,t}^{output/ha}}{\partial NEG_{i,t} \partial \boldsymbol{HIV_{i,t}}} = \boldsymbol{\phi_1} + 2 * NEG_{i,t} \boldsymbol{\phi_2} . \qquad (3)$$

Eq. (3) multiplied by 100 gives the estimated *change* (in percentage points) in the impact of a negative rainfall shock on crop output/ha given a one-percentage point increase in the HIV

[8] Low rainfall districts - up to 1,000 mm per year; high rainfall districts - greater than 1,000 mm per year. Low land-to-labor ratio districts - less than one hectare of arable land per adult aged 15 to 59 (ha/adult); high land-to-labor districts - greater than one ha/adult. Chow tests indicate that the impacts of HIV/AIDS and other regressors vary by rainfall group and by land-to-labor ratio stratum.

prevalence rate, *ceteris paribus*. (The first derivative, $\partial \log Y_{i,t}^{output/ha} / \partial NEG_{i,t}$, multiplied by 100 gives the estimated percentage change in output/ha given a one-percentage point increase in the negative rainfall shock.) Because there are no rainfall shocks in the area planted model (Eq. 1), the only way rainfall shocks affect crop output is via crop output/ha. Therefore, Eq. (3) also gives the change in the impact of a negative rainfall shock on crop output given a one-percentage point increase in HIV prevalence. We evaluate Eq. (3) at the mean, 75th percentile and 90th percentile of *NEG,* and henceforth refer to these as moderate, severe and extreme droughts, respectively. A statistically significant and negative partial effect in Eq. (3) supports the NVF hypothesis that HIV/AIDS exacerbates the effects of drought.[9]

A summary of the partial effect estimates per Eq. (3) is presented in Table 3, columns C, D, and E. For Zambia overall, there is no statistically significant evidence that HIV/AIDS exacerbates the effects of drought on crop output/ha. The partial effects of HIV/AIDS on the impacts of moderate and severe droughts are negative (-0.107 and -0.067, respectively), but these estimates are imprecisely measured (p>0.10) (Table 3, columns C and D).

In models stratified by rainfall level, results indicate that although HIV/AIDS worsens the effects of moderate drought on output/ha in low rainfall areas, none of the interaction effects between HIV/AIDS and drought are statistically significant at the 10% level in high rainfall districts (Table 3, columns C through E). In low rainfall areas, a one-percentage point increase in the HIV prevalence rate increases the negative effect of moderate drought by 0.15 percentage points (p=0.066). For example, the partial effect of a one-percentage point increase in the moderate drought shock is to reduce crop output/ha by 0.45% when HIV prevalence is 14% (the mean HIV prevalence for low rainfall areas); the negative effect of moderate drought increases to -0.60% when HIV prevalence is 15% (i.e., when HIV prevalence increases by one percentage point).

[9] Throughout the paper, unless otherwise specified, we use the 10% level as the cutoff for statistically significant parameter estimates.

Interestingly, results in low rainfall areas also indicate that an increase in the HIV prevalence rate *mitigates* the impacts of extreme drought. This finding could be due to the relief and development activities of civil society groups and development agencies in drought-prone areas (i.e., low rainfall districts). These programs often target vulnerable groups including HIV/AIDS-affected households.[10] If these programs are: (a) more active when drought shocks are relatively severe; (b) more active in areas with relatively high HIV prevalence rates; and (c) involve activities that directly or indirectly decrease targeted households' sensitivity to drought, then it is conceivable that the effects of extreme drought could be *less* negative in high HIV prevalence areas, whereas moderate droughts are exacerbated by HIV/AIDS.[11]

Results indicate that HIV/AIDS exacerbates the effects of severe and extreme drought on crop output/ha in high land-to-labor ratio areas, where labor is more likely to become a binding constraint on agricultural production, but no negative interactions between HIV/AIDS and drought are found in low land-to-labor ratio areas (Table 3, columns C through E). In high land-to-labor ratio districts, the negative effects of severe and extreme drought increase by 0.11 and 0.15 percentage points, respectively, when the HIV prevalence rate increases by one percentage point. For example, when HIV prevalence is 11% (the mean in high land-to-labor ratio areas), the partial effect of a one-percentage point increase in the extreme drought shock is to reduce crop output/ha by 0.45%; however, when HIV prevalence is 21% (the 90th percentile in these areas), the partial effect of extreme drought is to reduce crop output/ha by 1.95%. That is, the negative effect of extreme drought increases by 1.5 percentage points when the HIV prevalence rate increases by 10 percentage points. High resilience but high labor requirement famine coping strategies such as agricultural wage labour for harvesting, gathering wild foods, and producing crafts, are likely to be less available in high land-

[10] For example, the World Food Programme's (WFP) target districts in Zambia are concentrated mainly in low rainfall districts (natural regions I and II) (WFP, 2007, pp. 23-24) and high HIV prevalence areas are a main focus for WFP activities in the country (WFP, 1997; WFP, 2002; WFP, 2007).

[11] Ideally, we would control for relief and development activities in our model but the necessary district-level panel data are not available.

to-labor districts (de Waal and Tumushabe, 2003), which could explain why such areas appear to be more vulnerable to the NVF scenario wherein HIV/AIDS worsens the effects of drought.

In addition to determining if HIV/AIDS exacerbates the effects of drought, our other main objective is to determine the marginal effects of HIV/AIDS on agricultural production. To determine the partial effect of a one-percentage point increase in HIV prevalence on area planted and crop output/ha, we take the partial derivatives of Eqs. (1) and (2) with respect to ***HIV*** to get:

$$\partial \log AREA_{i,t} / \partial \boldsymbol{HIV}_{i,t} = \boldsymbol{\delta_1} + 2 * \boldsymbol{HIV_{i,t}\delta_2} \tag{4}$$

$$\partial \log Y_{i,t}^{output/ha} / \partial \boldsymbol{HIV}_{i,t} = \boldsymbol{\delta_1} + 2 * \boldsymbol{HIV_{i,t}\delta_2} + POS_{i,t}\boldsymbol{\varphi_1} + POS_{i,t}^2\boldsymbol{\varphi}_2 + NEG_{i,t}\boldsymbol{\phi_1} + NEG_{i,t}^2\boldsymbol{\phi}_2 \ . \tag{5}$$

Multiplying these partial derivatives by 100 gives the approximate percentage change in the agricultural production indicator given a one-percentage point increase in the HIV prevalence rate, *ceteris paribus*. We evaluate Eqs. (4) and (5) at the mean and 90th percentile of HIV prevalence and hold rainfall in Eq. (5) at the long-term average (i.e., we set *POS* and *NEG* to zero). We compute the partial effect of HIV/AIDS on crop output as the combined effects of HIV/AIDS on area planted and crop output/ha:

$$\partial \log Y_{i,t}^{output} / \partial \boldsymbol{HIV}_{i,t} = [(1 + \partial \log Y_{i,t}^{output/ha} / \partial \boldsymbol{HIV}_{i,t}) * (1 + \partial \log AREA_{i,t} / \partial \boldsymbol{HIV}_{i,t})] - 1 \tag{6}$$

A statistically significant and negative partial effect in Eq. (4), (5), or (6) is consistent with the conclusion that HIV/AIDS has a negative impact on agrarian livelihoods. The long-run partial effects of HIV/AIDS are summarized in Table 3, columns A and B. [12]

For Zambia overall (all districts), when HIV prevalence is at mean levels (approximately 12%), a one percentage point increase in the prevalence rate is associated with a 3.36% decrease in crop output/ha but a 4.34% increase in area planted in the long-run; the net result is no statistically

[12] Because our models include both contemporaneous and lagged HIV prevalence rates, there are both short-run (i.e., at a given lag) effects and long-run (i.e., total) effects of HIV/AIDS on the agricultural production indicators. We focus on the long-run effects in our discussion of the results because the HIV prevalence variables at various lags are highly collinear (even when we use Almon lags), which renders the short-run partial effect estimates less reliable. However, the estimates of the long-run effects should be more precisely measured.

significant change in crop output (Table 3, column A). However, when HIV prevalence is high (approximately 21%), a one percentage point increase in the prevalence rate results in a decrease in crop output/ha (-4.69%); the partial effect on area planted (-2.18%) is not statistically significant at the 10% level (Table 3, column B). The net effect is a statistically significant 6.77% decrease in crop output.

These results suggest that an initial strategy to cope with the epidemic adopted by agrarian communities may be to shift from intensive agricultural production (e.g., using improved seed, fertilizer, or other purchased inputs, and/or cultivating higher value crops) to more extensive production practices to maintain overall crop output levels. This would be consistent with the findings of a negative effect of HIV/AIDS on crop output/ha but a positive effect on area planted when HIV prevalence is at mean levels. The positive partial effect of HIV/AIDS on area planted at mean HIV prevalence levels might also be due to recruitment by HIV/AIDS-afflicted households of additional household members when a family member falls sick or dies. Several studies suggest that households 'replace' or 'replenish' members to maintain their household size after a prime-age death (Donovan et al., 2003; Yamano and Jayne, 2004; Mather et al., 2004; Mather et al., 2005; Chapoto and Jayne, 2008). Newly recruited household members may be in better health or physical condition than the ill or deceased household member they replace, and thus may be able to help the household expand their area under cultivation, even as the household's ability to invest in cash inputs is undermined by increased expenses due to HIV/AIDS-related morbidity and mortality.[13] However, the finding of no statistically significant effect of HIV/AIDS on area planted at high HIV prevalence levels indicates that this strategy of shifting to more extensive agricultural production to maintain total crop output in the face of lower output/ha is not viable when the epidemic is very severe in a

[13] These findings along with a marked pattern of counter-urbanization or urban-to-rural migration in Zambia suggest that a positive effect of HIV/AIDS on mean household area planted at the district level is plausible (Potts, 2005).

given community. At high levels of district HIV prevalence, both mean household crop output/ha and crop output decline.

We find that in low rainfall districts, HIV/AIDS has a positive and statistically significant partial effect on area planted when HIV prevalence levels are at their mean; however, combined with a weak negative effect of HIV/AIDS on crop output/ha, the increase in area planted is insufficient to have a statistically significant positive effect on overall crop output (Table 3, column A). At high HIV prevalence levels (column B), the partial effects of HIV/AIDS are imprecisely measured, but there is suggestive evidence that crop output/ha declines when HIV prevalence increases (-6.91%, p=0.134). In high rainfall areas, an increase in the HIV prevalence rate from mean levels is associated with a decline in area planted (-7.15%); none of the other partial effects of HIV/AIDS are statistically different from zero (Table 3, columns A and B).

Results also indicate that HIV/AIDS has a negative effect on mean household output/ha and crop output in both low and high land-to-labor ratio districts (Table 3, columns A and B). In low land-to-labor districts, a one percentage point increase in the HIV prevalence rate from its mean is associated with decreases of 6.88% and 5.84% in output/ha and crop output, respectively. In high land-to-labor districts, a one percentage point increase in the HIV prevalence rate from high levels is associated with decreases of 7.21% and 6.42% in output/ha and crop output, respectively.

6. CONCLUSIONS

Using nationally-representative district-level panel data from Zambia (1991/2-2004/5), this study empirically tests two key predictions of the NVF hypothesis: (1) that HIV/AIDS is causing a decline in agrarian livelihoods; and (2) that HIV/AIDS interacts with and exacerbates the effects of drought shocks. We estimate several supply response models to determine the effects of HIV/AIDS, drought shocks, and their interactions on mean household crop output, crop output/ha, and area planted (which we refer to collectively as 'agricultural production indicators'). The study contributes

to the evidence base concerning the NVF hypothesis specifically and the relationship between HIV/AIDS and smallholder agricultural production more generally.

The analysis generates two key findings. First, in several of the models estimated, we find that a one-percentage point increase in the district HIV prevalence rate is associated with a 3.4% to 7.2% reduction in mean household crop output, output/ha, or area planted in the long run. These findings are consistent with the NVF prediction that HIV/AIDS is eroding agrarian livelihoods. For Zambian districts overall, we find that a one-percentage point increase in the HIV prevalence rate from already high levels (approximately 21%) results in statistically significant ($p<0.10$) declines in district-level mean household crop output/ha (-4.7%) and crop output (-6.8%) in the long run. HIV/AIDS has significant negative effects on crop output and output/ha in both low and high land-to-labor ratio districts, and on area planted in high rainfall districts.

Second, while we find no evidence of significant negative HIV/AIDS-drought interactions for Zambia overall, or in high rainfall or low land-to-labor ratio districts, HIV/AIDS appears to worsen the effects of moderate drought in low rainfall areas and the effects of severe and extreme drought in high land-to-labor ratio areas (where HIV/AIDS may be more likely to cause labor to become a binding constraint on agricultural production). The negative effects of drought are found to increase by 0.11 to 0.15 percentage points when the HIV prevalence rate increases by one percentage point. These findings support the NVF hypothesis.

During the period of analysis (1991/2-2004/5), NVF-type outcomes (narrowly defined as negative interactions between HIV/AIDS and drought) appear to have been most likely in low rainfall areas (agroecological regions I, IIa, and IIb) and in districts with high HIV prevalence levels and high land-to-labor ratios. If these findings hold during future droughts in Zambia, then drought relief interventions may be particularly needed in such areas. However, results suggest that even in areas where there is no evidence of negative HIV/AIDS-drought interactions (i.e., low land-to-labor ratio or high rainfall districts), the epidemic still has negative direct effects on agricultural

production. Therefore, policies and programs to mitigate the impacts of HIV/AIDS on smallholder agriculture are needed throughout the country and even in good rainfall years.

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Table 1. *Summary statistics*

Variable	Abbrev.	Obs.	Mean	Std. Dev.	Min.	Max.
Mean household Divisia crop output index	$Y_{i,t}^{output}$	714	2.063	1.985	0.217	17.637
Mean household crop output/ha	$Y_{i,t}^{output/ha}$	714	1.618	1.508	0.202	13.487
Mean household area planted (ha)	$AREA_{i,t}$	714	1.373	0.535	0.170	3.725
Divisia crop output price index (t-1)	$P_{i,t-1}^{Y}$	663	7.698	6.912	1.000	39.145
Median fertilizer price (ZMK/kg)	$P_{k,t}^{fert}$	126	931.889	647.532	12.221	3,001.190
National private sector wages (mean ZMK/month)		14	302,498	301,893	8,961.61	1,113,861
Divisia livestock price index	$P_{k,t}^{lstock}$	126	17.534	14.930	1.000	57.107
Estimated HIV prevalence rate (%)	$HIV_{i,t}$	714	12.004	7.150	1.529	34.513
Mean seasonal rainfall (mm)		714	956.949	230.988	360.000	1598.823
Mean positive rainfall shock (% deviation from 16-year average rainfall)	$POS_{i,t}$	714	7.498	11.763	0	78.184
Mean negative rainfall shock (% deviation from 16-year average rainfall)	$NEG_{i,t}$	714	7.830	10.833	0	59.984

Sources: Data sources are as described in Section 3, "Data and variable construction".
Notes: i and *k* subscripts indicate district- and provincial-level variables, respectively.

Table 2. *AIC-minimizing lag structures for the HIV prevalence variable*

Dependent variable	Rainfall stratum		Land-to-labor ratio stratum		All districts
	Low (≤ 1,000 mm)	High (> 1,000 mm)	Low (≤ 1 ha/adult)	High (> 1 ha/adult)	
Crop output/ha	Dist. (t-2)	Almon (t-4)	Dist. (t-2)	Dist. (t-2)	Almon (t-4)
Area planted	Almon (t-6)	Dist. (t-2)	Almon (t-6)	Dist. (t-2)	Almon (t-6)
Number of districts	25	26	32	19	51

Notes: Almon = quadratic Almon lag structure; Dist. = distributed lag structure; (t-J) = HIV prevalence lagged up to J lags.

Table 3. *Summary of results*

Districts	Dependent variable	*Partial effects based on Eqs. 4, 5, & 6:* Long-run % change in the dependent variable given a one-percentage point increase in HIV prev. (evaluated at ___ HIV prevalence and average rainfall)		*Partial effects based on Eq. 3:* Percentage point *change* in the negative rainfall shock effect on **crop output/ha** & **crop output** given a one-percentage point increase in HIV prev. (evaluated at ___ negative rainfall shock)		
		Mean	High (90th percentile)	Mean (moderate drought)	75th percentile (severe drought)	90th percentile (extreme drought)
		(A)	(B)	(C)	(D)	(E)
All districts	Area planted	4.336* (s.e.=1.641, p=0.011)	-2.183 (s.e.=2.081, p=0.299)			
	Crop output/ha	-3.363+ (s.e.=2.009, p=0.100)	-4.690+ (s.e.=2.614, p=0.079)	-0.107 (s.e.=0.073, p=0.152)	-0.067 (s.e.=0.048, p=0.171)	0.027 (s.e.=0.071, p=0.706)
	Crop output	0.827 (s.e.=2.301, p=0.719)	-6.770* (s.e.=3.376, p=0.045)			
Low rainfall (≤ 1,000 mm)	Area planted	4.128** (s.e.=1.209, p=0.002)	0.634 (s.e.=2.766, p=0.821)			
	Crop output/ha	-2.221 (s.e.=2.965, p=0.461)	-6.914 (s.e.=4.462, p=0.134)	-0.154+ (s.e.=0.080, p=0.066)	0.024 (p=0.043, p=0.579)	0.247** (s.e.=0.072, p=0.002)
	Crop output	1.815 (s.e.=2.760, p=0.511)	-6.324 (s.e.=6.285, p=0.314)			
High rainfall (> 1,000 mm)	Area planted	-7.146+ (s.e.=3.569, p=0.056)	-2.278 (s.e.= 6.036, p=0.709)			
	Crop output/ha	2.136 (s.e.= 2.983, p=0.481)	3.478 (s.e.= 4.079, p=0.402)	-0.041 (s.e.=0.099, p=0.683)	-0.008 (s.e.=0.065, p=0.906)	0.088 (s.e.=0.090, p=0.338)
	Crop output	-5.162 (s.e.= 4.542, p=0.256)	1.121 (s.e.= 6.468, p=0.862)			
Low land-to-labor (≤ 1 ha/adult)	Area planted	1.111 (s.e.=1.934, p=0.570)	-0.501 (s.e.=2.913, p=0.864)			
	Crop output/ha	-6.875* (s.e.= 2.986, p=0.028)	-0.149 (s.e.= 2.849, p=0.959)	0.011 (s.e.= 0.069, p=0.877)	0.030 (s.e.= 0.045, p=0.504)	0.066 (s.e.=0.085, p=0.442)
	Crop output	-5.841+ (s.e.=3.507, p=0.096)	-0.650 (s.e.=2.717, p=0.811)			
High land-to-labor (> 1 ha/adult)	Area planted	2.049 (s.e.=2.819, p=0.477)	0.853 (s.e.=3.454, p=0.808)			
	Crop output/ha	-0.967 (s.e.=3.133, p=0.761)	-7.209* (s.e.=3.120, p=0.033)	-0.095 (s.e.=0.100, p=0.354)	-0.109+ (s.e.=0.061, p=0.090)	-0.150* (s.e.=0.057, p=0.017)
	Crop output	1.062 (s.e.=3.329, p=0.750)	-6.417+ (s.e.=3.359, p=0.056)			

Notes: + significant at 10% level; * significant at 5% level; ** significant at 1% level. Reported standard errors (s.e.) are heteroskedasticity- and serial correlation-robust