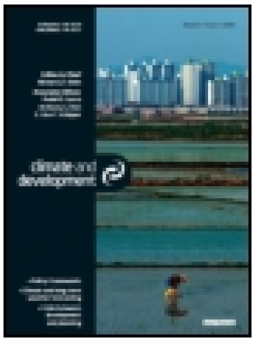

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Shock interactions, coping strategy choices and household food security

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ABSTRACT
Agriculture-based livelihoods in developing countries are often challenged by a multitude of unforeseeable shocks, but economic research mostly focuses on single shocks. This paper investigates how climate, health, pest and price shocks individually and in combination relate to farm households' coping strategy choices. First, we use binary probit models to examine how interactions from coinciding shocks relate to coping strategy choices. Next, we assess how coping strategies relate to household food security in a recursive framework. We find that when shocks are considered individually, the nature of shocks and their duration affect the likelihood of using savings. However, when climate shocks interact with health, pest or price shocks, there are incremental effects that increase the probability of depleting household assets to cope. Our findings suggest that governmental and non-governmental organizations should support rural farm households in managing the effects of multiple shocks through the provision and enhancement of markets for labour, insurance and outputs as well as formal safety nets. This support will help them to protect their assets and foster long-term wealth creation for escaping chronic poverty and food insecurity.

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Asset depletion; food security; incremental effects; shock interactions; Ghana

1. Introduction

The 2017 Sustainable Development Goals (SDGs) report highlights that economic shocks, natural disasters, conflict and wars, among other shocks, create economic losses of more than USD 250 billion annually. These various shocks usually affect both farm and off-farm activities of the rural poor and the vulnerable in developing countries, thus creating significant threats to their food security. Yet the current literature has mainly assessed shocks in isolation, although many rural farm households manage multiple risks concurrently (Béné et al., 2017; Dercon, 2002; Heltberg et al., 2015; Kalaba et al., 2013; Tongruksawattana & Wainaina, 2019). This pattern was addressed in a review article authored by Komarek et al. (2020), in which they examine multiple risks in agriculture that are present during 1974–2019 and raise concerns about the limited attention this topic receives, especially in the context of developing countries. Given that farm households have to manage multiple shocks, their *ex ante* risk management and *ex post* coping strategy choices may differ from those under the condition of individual isolated shocks due to possible incremental effects of shock interactions on welfare outcomes, e.g. food security. Detailed empirical evidence on how incremental effects of shock interactions relate to coping strategies is, however, rare. This paper investigates whether experiencing coinciding shocks leads to the choice of different coping strategies compared with those chosen in response to individual shocks. In doing so, we define a shock as *any event which may disrupt the normal functions of socioeconomic agents and/or their activities, impose challenges and threaten household food security* (Ansah et al., 2019).

Our motivations for assessing multiple shocks are as follows: First, it generates more complete insights by exposing combined effects beyond individual isolated shock effects (Komarek et al., 2020). Second, studies show that multiple shocks and their combined reinforcing effects on welfare are the main causes of vulnerabilities (Leichenko et al., 2010; O'Brien et al., 2009). Third, projections indicate that future shocks from climate change, urbanization and socioeconomic changes are likely to increase and occur simultaneously (FAO, 2016, 2017; Rosenzweig et al., 2014; Wheeler & von Braun, 2013). This shift will affect the nature and the effectiveness of coping and adaptation strategies to shocks (Intergovernmental Panel on Climate Change, 2019).

Two empirical studies so far demonstrate the need for further consideration of multiple shocks. Mazumdar et al. (2014) analyse how health shock acts as an 'intensifier' after a climate shock in India. They find that food consumption, school enrolment and medical treatment are worsened for households that suffer from health shocks after a climate shock. Lazzaroni and Wagner (2016) use two-period panel data to examine how the interaction of price and drought shocks affects child health in rural Senegal, concluding that multiple shocks worsen health problems. These studies account for interactions among a limited number of shocks, but they do

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not look specifically at how shock interactions influence coping strategy choices.

We build on these studies by using household data to address two main objectives. First, we assess how *ex post* coping strategy choices differ between those in response to single shocks and to coinciding shocks. Second, we investigate to what extent the *ex post* coping strategies relate to household food security. We include combinations of all possible shocks farm households face and multiple coping strategy choices.

This study contributes to the literature in two ways. First, we systematically assess multiple shocks, relating specific shocks and their combinations to specific *ex post* coping strategy choices and food security. This is relevant as not all strategies may be effective against individual shocks in contrast to coinciding shocks, and vice versa. Second, we provide knowledge on how specific strategies respond to coinciding shocks, which is key for informing implementation strategies, especially given the attention that strategies for building resilience against multiple vulnerabilities currently receive from humanitarian agencies and international development organizations (EU, 2012; USAID, 2012, 2016).

Section 2 outlines the conceptual framework from which we derive the study hypotheses. Section 3 explains the empirical strategy. Section 4 discusses the results, and Section 5 details the conclusions and implications of our study.

2. Conceptual framework

2.1. Literature on coping strategies

Economic literature discusses coping mechanisms mostly in the context of income shocks, which may emerge from, among others, droughts, floods, illnesses, pests or diseases. Mechanisms for dealing with income shocks are broadly discussed under asset smoothing and consumption smoothing. However, the distinction between coping strategies for asset smoothing and consumption smoothing is not always clear-cut.

With regard to asset smoothing, households aim for preserving productive assets for income generation even in bad times. Studies discussing asset smoothing identify portfolio diversification, including production, employment and economic activity choices (Dercon, 2002; Morduch, 1995). Strategies for asset smoothing are often *ex ante* measures with low transaction and opportunity costs that enable households to absorb short-run impacts of shocks (DeLoach & Smith-Lin, 2018). Other studies discuss *ex post* asset smoothing strategies, such as decreasing consumption, skipping meals or relying on social networks (Échevin & Tejerina, 2013; Kazianga & Udry, 2006; Zimmerman & Carter, 2003). Ashraf and Routray (2013) find that households reduce both their number of meals per day and number of purchases of expensive items to cope with income loss due to droughts.

For consumption smoothing, households accrue assets in good times and deplete them in bad times to maintain consumption (Deaton, 1991; Rosenzweig & Wolpin, 1993). Zimmerman and Carter (2003) distinguish between productive assets, such as livestock and land, and non-productive assets, such as cash savings and stored grains. Households facing health shocks such as illness of household members may sell livestock or use their savings to smooth consumption (DeLoach & Smith-Lin, 2018; Islam & Maitra, 2012; Isoto et al., 2017). When facing droughts, some households smooth consumption by depleting their livestock or grain stocks (Fafchamps et al., 1998; Kazianga & Udry, 2006). If labour markets exist, households also smooth consumption by participating more in off-farm work (Heltberg et al., 2015; Kochar, 1995, 1999).

In general, households with more assets tend to be more resilient and able to cope better with shocks. However, the specific assets used for coping depend on the severity of the shock(s). For instance, Paul (1998) observed that (productive) assets are not generally depleted under normal drought conditions, but it is the intensification effect that forces households to deplete assets.

2.2. Individual and coinciding shocks, coping strategies and food security: a conceptual model and hypotheses

The literature discussed suggests that coping strategy decisions depend on the shock characteristics (see Figure 1). These characteristics relate to the nature of shocks (Lokonon, 2019). A shock may be caused by the climate or weather, e.g. drought or floods; human health problems, e.g. illness or the death of a household member; pests, e.g. crop pest infestation or animal diseases, or price shocks, e.g. high food/input prices. Their nature also determines whether the shock is idiosyncratic (affecting individual households) or covariate (affecting many households in a given location). Moreover, their frequency, intensity (severity of shock) and duration (how long the shock remains) are crucial characteristics. Households may be hit by an isolated individual shock, a sequence of two or more shocks that may be independent of the other or related in a cascade-like way or two or more coinciding shocks.

Food security is challenged by these shocks in a number of ways. For example, drought or crop diseases reduce crop yields. Low yields cause high prices (Harvey et al., 2014) in local markets, making food more expensive, reducing purchasing power and lowering calorie intake (Ecker & Qaim, 2011). High food prices often hurt the poorest quintile of the population, which includes many farm households (Magrini et al., 2017). Furthermore, illness or the death of household members reduces household labour allocation and increases health or funeral expenditures (Lim, 2017), all of which reduces household income and calorie intake.

Whether occurring in isolation or coincidentally, shocks lead to either real income loss (Møller et al., 2019) by reducing profits or increasing the costs of consumption or the destruction of assets, the death of livestock by fire. In the case of individual shocks, the coping strategies a household would choose in order to minimize the effects on its welfare largely depends on the costs, i.e. real income loss or direct asset loss, caused by these shock characteristics. More intense shocks may cause higher costs such that households would be forced to adopt different coping strategies than when dealing with mild shocks. For instance, if a household head is hit by a health shock, e.g. became infected with malaria for few days, it may barely destabilize household food consumption even though this person may not be able to generate income for a few days. Household savings may be sufficient to help maintain

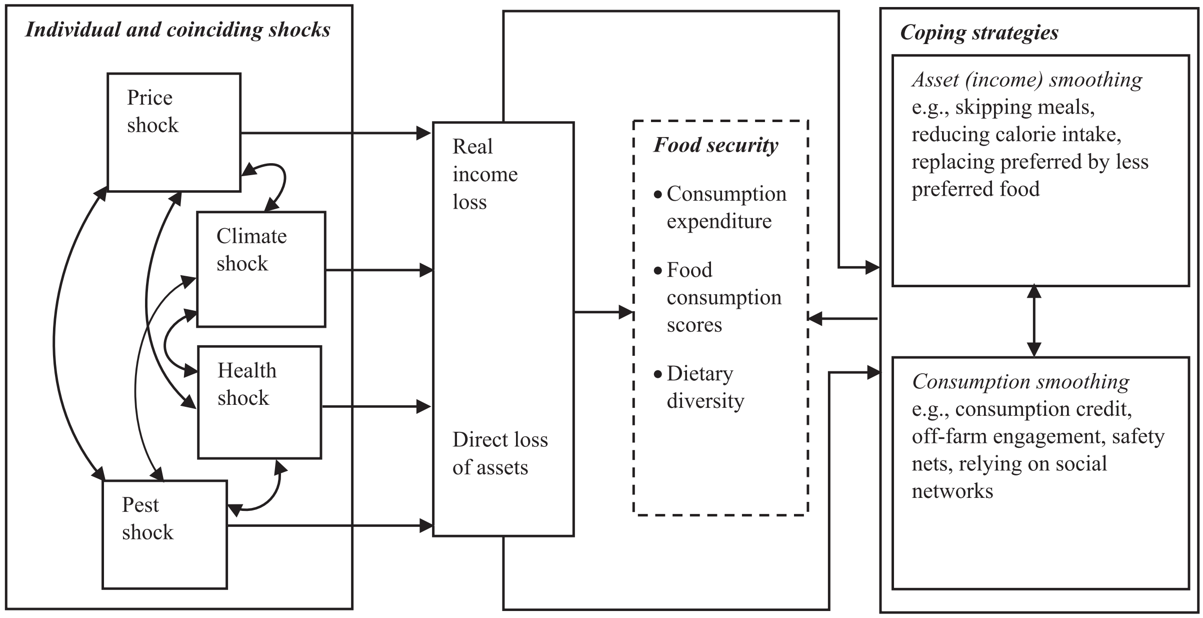

Figure 1. Conceptual framework linking shocks, coping strategies and food security. Source: Authors.

household food security in the case that the household head is unable to maintain previous income levels during that period. However, a more intense shock, such as extended drought for weeks at the start of a cropping season, may lead households to deplete assets in order to maintain pre-shock food consumption levels, especially when their savings are not sufficient for coping.

When shocks coincide, the separate effects of the individual shocks on household food security, via real income and/or asset loss, may interact and reinforce each other, producing a composite effect that differs from the sum of the isolated shocks. We call this additional effect an *incremental effect*. For example, when a bad crop harvest coincides with or is closely followed by high food prices, the resulting effect on household food security is likely to be more pronounced than it would be if both individual shocks had occurred at different times. When they coincide, the bad harvest may lead to a lower income at the same time the household needs to purchase food at higher prices. Thus this household suddenly faces a situation that will severely challenge its food security since it needs to supplement the reduced subsistence production with purchased food that is more expensive than usual. Assume that another household is hit by a crop failure, e.g. due to a fire that destroyed large parts of its harvest, but harvests of other farmers are at average levels. Maintaining household food security will be less challenging in this latter case as consumption expenditures at average prices will be much lower in the latter than in the former case. If this household is only hit by high food prices while it has an average harvest, the effect on its food security may be negligible since it produces all of its own food and the average harvest prevents the household from needing to purchase food at those elevated prices. Hence, an incremental effect caused by the concurrence of two or more shocks may force the household to choose different coping strategies.

Alternatively, coinciding shocks may neutralize each other's effects on real income or assets, thus requiring no coping. For instance, consider a semi-commercial farm household facing a drought. Even though the drought is likely to cause low yields, effects of this shock can be offset by the increased prices in the local market, which are caused by limited general supply.[1] Consequently, the income of the household may not be affected in any way even though it was exposed to two coinciding shocks.

We assess to what extent such incremental effects affect the choice of coping strategies, that is to say to what extent differences exist between the coping strategy choices of farm households exposed to isolated individual shocks and those exposed to coinciding shocks that may interact by neutralizing or reinforcing each other. To mitigate or moderate the effects of shocks on income and asset losses, households will choose from a portfolio of coping strategies at their disposal. Hence, we hypothesize that the type(s) of coping strategies chosen also depends on the characteristics of the shocks, including their idiosyncratic or covariate nature.

All else equal, we suppose that if coinciding shocks have a reinforcing interaction effect, a strategy that helps households to cope with an isolated individual shock may no longer be effective due to the incremental effect of shock interactions. Given an incremental effect of the concurrence or closely temporal sequence of two or more shocks, households may need to use their savings to counterbalance the resulting real income loss to maintain or re-achieve food consumption at the pre-shock level. However, if savings are insufficient, the household may be forced to use additional strategies until all available options are exhausted and before productive assets need to be depleted. The choice of coping strategies depends on the objectives of the household, whether they are to smooth consumption or smooth assets. Households with asset smoothing motives may resort to temporarily changing consumption behaviour, such as skipping meals or reducing calorie intake.

Consumption smoothing households may borrow money from friends or credit institutions.

Zimmerman and Carter (2003) hypothesize that households respond differently to shocks depending on their level of assets. Hoddinott (2006) confirms this hypothesis empirically using panel data from rural Zimbabwe. Barrett et al. (2016) and Hoddinott (2006) argue that asset accumulation is crucial for escaping chronic poverty and reducing food insecurity. Ellis (2000) points out that asset depletion seems often to be the last option when households experience shocks with high impacts. These findings give rise to a first set of hypotheses on the effect of multiple shocks and their interactions on coping strategy choices.

> H1a: The number of experienced shocks matters in choosing coping strategies.
>
> H1b: Coinciding shocks have incremental effects on coping strategy choices.
>
> H1c: Incremental effects of coinciding shocks make households more likely to deplete assets than single shocks.

For farm households, the principal goal of coping with shocks is to maintain food security. Akter and Basher (2014) conclude that household food security in Bangladesh worsened because of the combined effects of the 2007–2009 food price shock and income shocks in the same period. According to Béné et al. (2015), the outcome of household food security is the resultant effect of a shock, a household's coping capacity, i.e. resilience, and the coping strategies that were applied.

Coping strategy choices affect food security through a number of pathways. If a household has adequate savings or assets or receives help from families and relatives, the effects of the real income loss on food security may be reduced or neutralized. But if adequate mechanisms are not feasible for the household, they may resort to negative coping behaviours such as reducing consumption, skipping meals or eating less preferred food. Eventually, households may deplete productive assets as a last option.

Corbett (1988) argues that when faced with recurrent shocks affecting consumption, farm households sequentially adopt coping strategies, starting with strategies that require minimum commitment of household productive assets. Ellis (2000) outlines five main coping mechanisms that are sequentially adopted when households face shocks that threaten food security. The first is anticipatory in nature, involving income diversification. The second draws on social networks. If these two mechanisms are insufficient for coping, the next is for some household members to migrate temporarily. Besides migration, households may deplete agricultural assets such as implements and livestock. If all these mechanisms fail, the last option is to deplete fixed assets such as land or buildings. In consideration of these findings, our second hypothesis is:

> H2: Asset depletion plays a moderation role under shock interactions to maintain food security.

3. Empirical strategy

We use data on shocks and coping strategies taken from the Ghana baseline survey of the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) project. This data is available publicly online and contains a report showing a map of the surveyed communities (International Food Policy Research Institute, 2015). We also include a customized map of the study area showing the districts, the number of communities and the number households surveyed in each district (see Figure 2). The data was collected in the 2013/2014 agricultural season through a quasi-randomized control trial designed to estimate the causal impacts of Africa RISING interventions on the target population. It includes qualitative measures of shocks and coping strategies used by farm households in northern Ghana. Farmers were asked to identify the various shocks they had experienced that severely and negatively affected their household's assets and/or income. Note that the magnitude of the various shocks was not measured. Moreover, due to the cross-sectional nature of the data, it does not assess successive shocks, which requires panel data, but it does assess combinations of shocks.

Our empirical strategy is as follows: Farm households identified 21 different shocks, including an 'other' category (see Section A1 and Tables A1 and A2 in the online appendix for details on all reported shocks and coping strategies), but only a few were frequent. Due to relatively low frequencies and similarities among most of these shocks, we categorize them into the four main groups of shocks discussed in the previous section of this paper in Figure 1, namely climate, pest, health and price shocks. Climate shocks include droughts, floods and storms. Pest shocks include crop pests, diseases and livestock pests or diseases. Health shocks include illness and the death of a household or family member. Price shocks include large increases in input or food prices and large dips in crop sale prices.

Faced with these shocks, farm households reported the different *ex post* strategies they used to cope.[2] We group the reported coping strategies into six main categories based on frequency use, nature and similarities among the strategies. The categories are: use of own cash savings, asset depletion (i.e. sale of assets, crop stocks, livestock, land or building); social networks (i.e. unconditional help from families and friends or other relations); consumption change (i.e. changed eating patterns or reduced consumption expenditures); safety nets (i.e. unconditional help from the government, NGOs or religious groups), and labour deployment (i.e. non-working adults take on employment, employed members take on more jobs or migration in search of jobs).

3.1. Investigating the effect of isolated and multiple shocks on coping strategy choices

To test *H1a*, we use binary probit models formulated in Equations (1) and (2) to examine how multiple shocks affect the likelihood of choosing each of the 6 coping strategy categories. In Model 1 represented by Equation (1), we investigate the relation between the number of shocks and each coping strategy choice[3]:

$$P(C_j) = 1|n, X) = G(b_0 + b_1 n + b_2 W + b_3 X) \qquad (1)$$

where a household's choice for adopting coping strategy category j is C_j, $(j = 1, \ldots, 6)$, the number of shock categories is

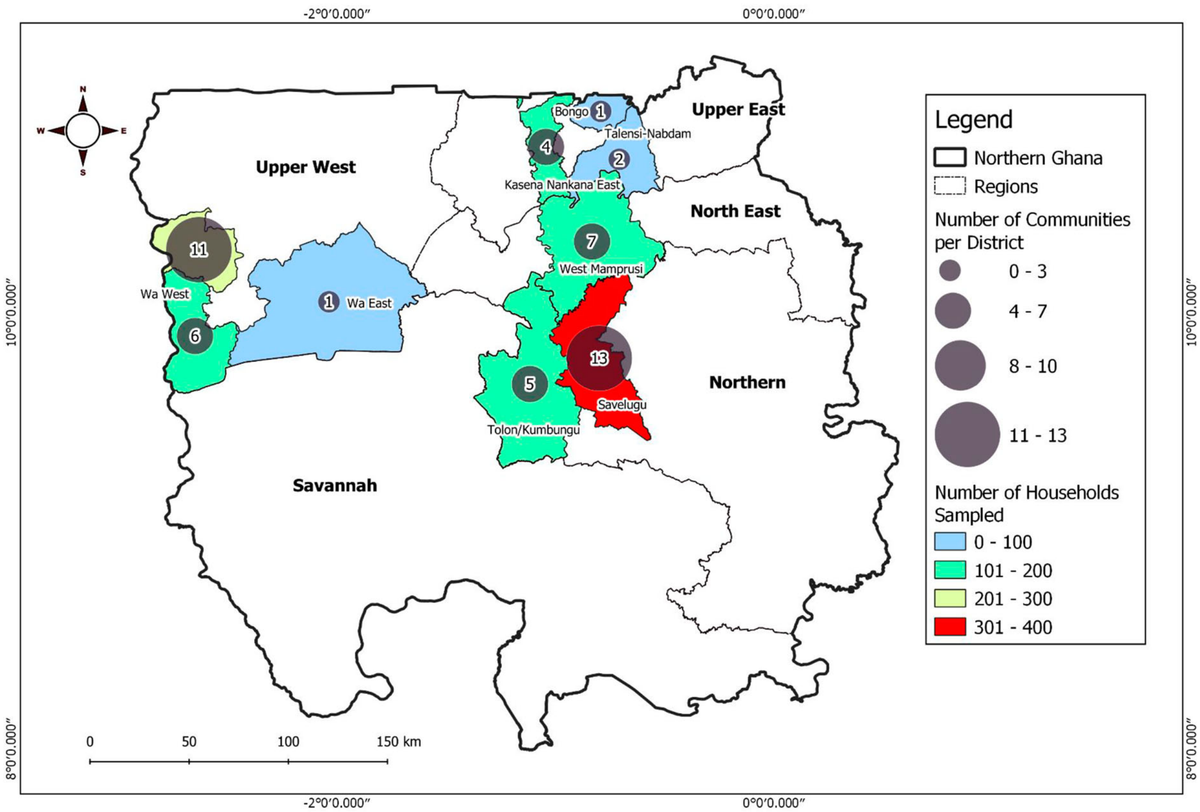

Figure 2. A map of Northern Ghana showing the surveyed districts, communities and number of households. Source: Authors, based on survey data 2014 (International Food Policy Research Institute, 2015).

n (= 0, 1, … 4), shock characteristics are W, control variables are vector X and G is the cumulative density function (CDF) of the standard normal distribution. In model (1), rejecting $b_1 = 0$ indicates that the number of shocks matters for choosing coping strategy C_j (*H1a*).

Next we test whether facing multiple shocks has incremental effects using probit model (2). This model has four dummy variables to indicate whether the household reported a certain number of shocks ($d_n = 1$) or not ($d_n = 0$). The no shock category ($n = 0$) is set as the benchmark. Here we assume that the intensity of each shock is fixed and that households do not experience the same category of shock multiple times.

$$P(C_j = 1|n, X) = G(b_0 + b_{11}d_1 + b_{12}d_2 + b_{13}d_3 + b_{14}d_4 + b_2W + b_3X) \quad (2)$$

We test sequentially whether the differences between the parameters, i.e. $b_{12}–b_{11}$; $b_{13}–b_{12}$; $b_{14}–b_{13}$, equal zero. Significant differences from zero indicate that being exposed to a higher number of shocks affects coping strategy choices. From model (2) we can then determine the incremental effect of additional shocks on coping strategy choices.

3.2. Analysing specific shock interactions and coping strategy choices

To test *H1b* and *H1c*, we use the probit model specified in Equation (3) to examine whether and to what extent specific shock categories and interaction effects influence coping strategy choices.

$$P(C_j = 1|s, X) = G(b_0 + \sum_{j=1}^{J} b_j s_j + \sum_{i=1}^{I}\sum_{j=1}^{J} b_{ij}s_is_j + b_2W + b_3X); \quad i \neq j \quad (3)$$

where each shock category, i.e. climate, health, pest and price shocks, is denoted by s_i. Equation (3) is estimated two times: once excluding the double summation term for shock categories and once for the complete model. In the complete model, the coefficient b_{ij} measures two-shock interaction effects. Rejecting b_i=0 and b_{ij}=0 indicates that two-shock interaction effects affect coping strategy choices.

3.3. Assessing the effect of coping strategy choices on food security

For testing *H2*, a key econometric concern is endogeneity. Endogeneity may arise from two sources. First, given that households may self-select (Heckman, 1979) and choose particular coping strategies and not others, food security and coping strategy choices may be interdependent. Unobserved factors influencing coping strategy choices may also influence food security. For instance, food-secure households might adopt more *ex ante* risk management strategies that make them more capable of coping with shocks than food-insecure households. Although food security may also influence coping strategy choices, we

Table 1. Marginal effects of the number of shocks on coping strategy choices.

Variables	(1) Savings	(2) Asset depletion	(3) Safety nets	(4) Labour deployment	(5) Consumption change	(6) Social networks
Number of shocks (n)	0.0021	0.1171***	−0.0123**	0.0146***	0.0004	−0.0058
	(0.0162)	(0.0132)	(0.0063)	(0.0053)	(0.0059)	(0.0141)
Idiosyncratic	0.1905***	0.0371	0.0122	0.0060	−0.0292***	0.0147
	(0.0269)	(0.0247)	(0.0106)	(0.0085)	(0.0113)	(0.0247)
Duration of shocks	−0.0681*	0.0557*	−0.0018	0.0245***	0.0225**	0.0769***
	(0.0349)	(0.0291)	(0.0132)	(0.0086)	(0.0100)	(0.0280)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1100	1100	1100	1100	1100	1100

Note: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

do not expect this to happen since households reported shocks that occurred in the past whereas the food security data is more recent (measured during the survey period). Second, endogeneity may arise from unobserved factors that may influence the choice of one coping strategy as opposed to the others.

To test *H2* given possible endogeneity, we use a recursive model by augmenting Equation (4) with Equation (5):

$$\Pr(C_{ij} = 1|s, X) = G(s'\alpha + X'b), \quad j = 1, 2, \ldots, J \quad (4)$$

$$FS = \gamma_0 + \gamma_1 s + \gamma_2 C_{ij} + \gamma_3 s C_{ij} + \gamma_4 X + u \quad (5)$$

where *FS* denotes a food security indicator (*HDDS*, *FCS*, *CSI*), s is a vector of shocks and their interactions, u is a normal error and the other symbols are as they were already defined. Given that coping strategy choices may be endogenous to food security, standard estimation methods may produce biased and inconsistent results. The recursive model helps to solve the endogeneity issue by jointly[4] estimating the coping strategy model (4) and the food security model (5) through maximum likelihood (Roodman, 2011). The multivariate probit model (4) is estimated, and then the predictions are incorporated in the linear food security model (5) in order to estimate its parameters. This model structure allows correlation among the variables, while controlling for the possible endogeneity of coping strategy choices in the food security model.

4. Results and discussion

This section presents the core estimation results. Complementary results as well as summary statistics of the data are provided in Section A1 and Appendix Tables A3–A6 of the online appendix.

4.1. Effects of single and multiple shocks on coping strategy choices

The results of the probit models (1) and (2) for testing hypothesis *H1a* are presented in Tables 1 and 2 respectively. The number of different shock categories experienced is significantly related to asset depletion, safety nets and labour deployment coping strategies. For shock characteristics, the results show that households reporting a severe idiosyncratic shock are more likely to choose savings but less likely to change consumption. If the average duration of shocks increases, the likelihood of choosing savings decreases, but the likelihood of choosing asset depletion, labour deployment, consumption change and social networks increases.

To confirm and estimate incremental effects of multiple shocks, we turn to the results of model (2). Even though facing any number of shocks increases the likelihood of choosing savings, the parameter differences between combined shocks are not significant. This result means that the incremental effects of shock interactions do not affect the likelihood of choosing savings as a coping strategy. In other words, whether a household faces a single shock or multiple shocks, savings can be used to cushion the effects. Moreover, this result implies that facing more than one shock does not have any significant increasing effect on choosing savings as a coping strategy. Rational households would first choose their available savings for coping with shocks. With regard to safety nets and labour deployment, multiple shocks, compared with single shocks, have no incremental effect on the likelihood of choosing such strategies.

Regarding asset depletion, both the number of shocks in model (1) as well as the parameter differences corresponding to an increasing number of shocks in model (2) (from 2 to 4 shocks) are significant. Holding the nature and duration of shocks constant, we can infer from this result that experiencing two or more shocks affects the likelihood of choosing asset depletion as a coping strategy. As discussed by Corbett (1988) and Ellis (2000), households tend to explore other low-cost options of coping, e.g. the use of cash savings when facing only one shock rather than depleting their productive assets. Furthermore, for households with savings, a single shock increases the likelihood to use their savings first instead of depleting their assets (Doss et al., 2018). The outcomes of the Chi-square tests on parameter differences for the reported number of shocks confirm this finding. Our significant test result means that for a household that is already experiencing a single shock, any additional shock increases the probability of depleting assets.

4.2. Specific shock interactions and incremental effects on coping strategy choices

Before discussing the results on shock interactions, we will briefly discuss the effects of individual shocks on coping strategy choices resulting from the probit regressions of Equation (3) for the six coping strategies. We include dummies for the climate, health, pest and price shock categories as the main covariates, while controlling for shock characteristics,

Table 2. Marginal effects of shock frequencies and statistical tests of equality of shock parameters.

Variables	(1) Savings	(2) Asset depletion	(3) Safety nets	(4) Labour deployment	(5) Consumption change	(6) Social networks
One shock (d1)	0.2903**	0.1134	−0.0374		0.1348	0.2310
	(0.1215)	(0.1558)	(0.0339)		(8.7210)	(0.1510)
Two shocks (d2)	0.3234***	0.2623*	−0.0352	0.2213	0.1776	0.2693*
	(0.1217)	(0.1551)	(0.0339)	(14.5051)	(8.7210)	(0.1514)
Three shocks (d3)	0.3145**	0.3950**	−0.0522	0.2253	0.1711	0.2483
	(0.1228)	(0.1549)	(0.0353)	(14.5051)	(8.7210)	(0.1521)
Four shocks (d4)	0.2280*	0.4292***		0.2457	0.1182	0.1520
	(0.1308)	(0.1588)		(14.5051)	(8.7210)	(0.1580)
Idiosyncratic	0.1918***	0.0384	0.0127	0.0069	−0.0296***	0.0161
	(0.0268)	(0.0247)	(0.0116)	(0.0125)	(0.0111)	(0.0246)
Duration of shocks	−0.0667*	0.0515*	−0.0036	0.0354***	0.0209**	0.0775***
	(0.0350)	(0.0293)	(0.0143)	(0.0124)	(0.0098)	(0.0280)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1100	1100	1009	762	1100	1100
Chi-square test of differences between the number of shocks						
d2 vs. d1 shock	0.76	17.48***	0.03	0.00	5.51**	1.44
d3 vs. d2 shock	0.06	21.16***	1.42	0.09	0.34	0.46
d4 vs. d3 shock	2.52	0.64	2.19	1.18	3.73*	3.52*

Note: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Empty spaces indicate insufficient observations to estimate parameters.

socioeconomic and demographic characteristics of the households as well as institutional factors such as access to health facilities, among others. Marginal effects are presented in Table 3; each column from the second to the last represents a specific coping strategy model.

Controlling for shock duration and the idiosyncratic nature of shocks, we infer from these results that individual climate, pest and price shocks correlate positively with asset depletion; pest and price shocks have a negative correlation with social networks; pest shock has an inverse correlation with savings; and price shocks correlate inversely with safety nets. A climate shock increases both the probability of a household using their savings as a coping strategy by 0.11 and the probability of them using asset depletion by 0.11, all else held constant. It does not lead to choosing social networks as a coping strategy, probably due to its covariate nature where many households in a given location may be affected. A pest shock increases the likelihood of choosing asset depletion and labour deployment, but reduces the likelihood of using savings and social networks. A health shock has a positive effect only on choosing social networks (0.192). A price shock directly affects asset depletion but reduces the likelihood of using safety nets and social networks.

The coefficients of the shock characteristics indicate that a severe idiosyncratic shock increases the likelihood of using savings and asset depletion but reduces the likelihood of altering consumption. On the other hand, as the average duration of shocks increases, the likelihood of choosing savings reduces while the likelihood of choosing labour deployment, choosing consumption alteration and using social networks increases. These results are plausible, particularly with regard to shock duration. Given the limited amount of savings rural farm households included in this study have, an extended shock episode means that their savings are likely to quickly become exhausted. Hence, alternative coping strategies like off-farm labour participation, relying on social networks and altering consumption must be engaged.

The results for the estimated b_i and b_{ij} in model (3) for testing *H1b* and *H1c* shown in Table 4 paint a clearer picture of how the incremental effects of shock interactions influence coping strategy choices. Based on the marginal effects, we quantify the incremental effects of specific shock interactions.

Two-shock interactions do not influence the choice of a household using their savings as a coping strategy. This finding strengthens the conclusions derived from the previous

Table 3. Marginal effects from binary probit coping strategy models that only include single shocks.

Variables	(1) Savings	(2) Asset depletion	(3) Safety nets	(4) Labour deployment	(5) Consumption change	(6) Social networks
Climate shock	0.1100***	0.1100***	−0.0118		0.0077	0.0286
	(0.0357)	(0.0324)	(0.0120)		(0.0144)	(0.0294)
Pest shock	−0.0895***	0.1174***	0.0024	0.0252**	0.0060	−0.0610**
	(0.0312)	(0.0259)	(0.0114)	(0.0128)	(0.0108)	(0.0269)
Health shock	0.0501	0.0415	0.0043	0.0033	0.0173	0.1919***
	(0.0341)	(0.0295)	(0.0131)	(0.0133)	(0.0130)	(0.0326)
Price shock	−0.0049	0.1553***	−0.0571***	0.0105	−0.0190	−0.0604**
	(0.0347)	(0.0274)	(0.0221)	(0.0130)	(0.0122)	(0.0303)
Idiosyncratic	0.1851***	0.0577**	0.0056	0.0123	−0.0333***	−0.0194
	(0.0277)	(0.0255)	(0.0108)	(0.0131)	(0.0115)	(0.0246)
Duration of shocks	−0.0671*	0.0442	0.0011	0.0342***	0.0259***	0.0917***
	(0.0353)	(0.0293)	(0.0129)	(0.0127)	(0.0100)	(0.0280)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1050	1050	1050	651	1050	1050

Note: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 4. Marginal effects from binary probit coping strategy models that include shock interactions.

Variables	(1) Savings	(2) Asset depletion	(3) Safety nets	(4) Labour deployment	(5) Consumption change	(6) Social networks
Climate shock	0.1382	0.3363***	−0.0374		0.2203	0.2540**
	(0.0970)	(0.1221)	(0.0387)		(9.4014)	(0.1290)
Pest shock	−0.0945	0.2650***	0.0121	0.0421	0.0908**	0.0358
	(0.0950)	(0.0880)	(0.0392)	(0.0260)	(0.0410)	(0.0914)
Health shock	0.1392	0.2842**	−0.0103	0.0033	0.2549	0.3564***
	(0.0922)	(0.1205)	(0.0350)	(0.0258)	(9.4014)	(0.1259)
Price shock	0.2124*	0.2890***	−0.5274	0.0316	−0.1384	0.0105
	(0.1162)	(0.0996)	(38.4437)	(0.0272)	(10.4379)	(0.1067)
Climate × pest	0.0628	−0.0656	−0.0143		−0.0434	−0.1177*
	(0.0833)	(0.0736)	(0.0317)		(0.0299)	(0.0694)
Climate × health	−0.0219	−0.1980*	0.0305		−0.2075	−0.2076
	(0.0975)	(0.1187)	(0.0393)		(9.4014)	(0.1286)
Climate × price	−0.1255	−0.1236	0.2631		0.2025	−0.0661
	(0.1028)	(0.0849)	(34.4722)		(10.4379)	(0.0844)
Pest × health	−0.0497	−0.1073*	−0.0017	−0.0013	−0.0257	0.0253
	(0.0687)	(0.0605)	(0.0333)	(0.0264)	(0.0305)	(0.0689)
Pest × price	−0.0431	−0.0393	0.2476	−0.0334	−0.0968***	−0.0674
	(0.0667)	(0.0544)	(17.0171)	(0.0258)	(0.0307)	(0.0580)
Health × price	−0.1284*	−0.0033		0.0005	−0.0497	0.0248
	(0.0709)	(0.0597)		(0.0255)	(0.0306)	(0.0718)
Idiosyncratic	0.1864***	0.0584**	0.0053	0.0140	−0.0333***	−0.0175
	(0.0279)	(0.0257)	(0.0131)	(0.0133)	(0.0112)	(0.0246)
Shock duration	−0.0754**	0.0393	−0.0001	0.0353***	0.0226**	0.0947***
	(0.0355)	(0.0298)	(0.0153)	(0.0131)	(0.0100)	(0.0282)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1100	1100	919	775	1100	1100

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

results that show that only one shock is sufficient for choosing savings. For asset depletion, it is a different story. While a single shock does not significantly relate to asset depletion, the incremental effect of two-shock interactions increases its likelihood. Comparing the estimates in Tables 3 and 4, we see clear differences in how coping strategy choices respond to individual and multiple shocks. Under shock interactions, there is an incremental effect that affects the likelihood of choosing a given coping strategy. For instance, both climate and health shocks have a significant positive effect, while their interaction term is significant and negative. The combined effect (0.3363 + 0.2842–0.1980 = 0.423) is larger than the sum of the individual shock effects as reported in Table 3 (0.11 + 0.0415 = 0.152). The value of 0.423 implies that when climate and health shocks coincide, the probability of depleting assets to cope is about 27% (0.423–0.152) higher than if any of the shocks separately affected the household at different times. We draw similar conclusions for the interaction of pest and health shocks. The combined effect (0.265 + 0.2842–0.1073 = 0.442) is larger than the sum of the individual effects (0.1174 + 0.0415 = 0.159). So the interaction between pest and health shocks makes a household more likely to deplete assets than the summed effect of the individual shocks by about 28% (0.442–0.159). For the remaining coping strategies, shock interactions do not seem to have any significant incremental effect.

When analysing coping strategies independently, the results indicate that shock interactions mainly affect the likelihood of depleting assets. On the other hand, when coping strategies are analysed simultaneously, the multivariate probit results in Table 5 further strengthen the findings that climate-health, climate-price and pest-health shock interactions increase the likelihood of depleting assets to cope with incremental effects. Based on these findings, hypothesis *H1c*, which states that the incremental effect of multiple shocks makes households more likely to deplete assets than single shocks, cannot be rejected. When controlling for shock characteristics, other coping strategies, particularly the use of savings, may be sufficient to cope with single shocks, in which case assets can be accumulated or invested to generate wealth. However, when shocks coincide the incremental effects force households to deplete stored assets to satisfy consumption goals.

4.3. Do coping strategies moderate the effect of shocks on household food security?

The results for testing *H2* using model (5) are reported in the second part of Table 5 for FCS, CSI and HDDS. Model performance across all three food security models shows statistically significant likelihood ratio (LR) chi-square statistics, indicating a good fit. The parameters ρ_{14}, ρ_{24} and ρ_{34} test for the correlation of unobserved factors affecting food security and the coping strategies. The results appear mixed, depending on the food security model used. In the CSI model, there is a significant positive correlation between savings and food security, asset depletion and food security as well as social networks and food security, which means that savings, assets and social networks are likely endogenous in the CSI function. However, in the HDDS and FCS models, only asset depletion has a significant negative correlation with food security, again confirming possible endogeneity of asset depletion in the food security model.

Consistent with *H2*, households that deplete assets have significantly higher scores on FCS and HDDS. Under climate shocks, farm households that deplete assets are able to maintain or improve the diversity of foods consumed. Also, the negative

Table 5. Recursive structural model results for food security and coping strategies.

Variable	Multivariate probit with CSI model			Multivariate probit with HDDS model			Multivariate probit with FCS model		
Variable	Savings	Asset depletion	Social networks	Savings	Asset depletion	Social networks	Savings	Asset depletion	Social networks
Climate shock	0.446*	1.018***	0.963**	0.430	1.114***	0.841*	0.384	1.252***	0.834*
	(1.94)	(3.16)	(2.07)	(1.56)	(2.58)	(1.89)	(1.38)	(3.06)	(1.77)
Pest shock	−0.136	0.920***	0.149	−0.265	0.936***	0.224	−0.261	0.975***	0.169
	(−0.60)	(3.80)	(0.43)	(−0.99)	(3.12)	(0.68)	(−0.97)	(3.39)	(0.49)
Health shock	0.355	0.845***	1.287***	0.391	0.988**	1.196***	0.370	1.047***	1.233***
	(1.63)	(2.67)	(2.83)	(1.49)	(2.34)	(2.75)	(1.39)	(2.62)	(2.67)
Price shock	0.376	1.168***	0.0173	0.692**	0.638*	0.253	0.635*	0.674**	0.147
	(1.33)	(4.39)	(0.04)	(2.05)	(1.81)	(0.65)	(1.89)	(1.99)	(0.37)
Climate × pest	0.0744	−0.341*	−0.484*	0.129	−0.171	−0.561**	0.168	−0.342	−0.457*
	(0.38)	(−1.74)	(−1.84)	(0.54)	(−0.69)	(−2.27)	(0.71)	(−1.44)	(−1.76)
Climate × health	−0.149	−0.446	−0.762	−0.0402	−0.701*	−0.582	−0.00360	−0.895**	−0.596
	(−0.66)	(−1.48)	(−1.64)	(−0.15)	(−1.69)	(−1.31)	(−0.01)	(−2.26)	(−1.27)
Climate × price	−0.172	−0.682***	−0.276	−0.427	−0.150	−0.419	−0.367	−0.219	−0.325
	(−0.70)	(−3.15)	(−0.86)	(−1.44)	(−0.50)	(−1.36)	(−1.24)	(−0.77)	(−1.03)
Pest × health	−0.0875	−0.417***	0.156	−0.128	−0.411**	0.0838	−0.151	−0.321	0.0722
	(−0.54)	(−2.59)	(0.60)	(−0.66)	(−2.02)	(0.34)	(−0.77)	(−1.64)	(0.28)
Pest × price	−0.0904	−0.130	−0.260	−0.132	−0.0442	−0.333	−0.111	−0.125	−0.260
	(−0.57)	(−0.91)	(−1.19)	(−0.69)	(−0.24)	(−1.56)	(−0.58)	(−0.71)	(−1.19)
Health × price	−0.267	−0.0620	0.142	−0.401**	0.0859	0.0475	−0.400**	0.151	0.0346
	(−1.57)	(−0.40)	(0.52)	(−1.99)	(0.43)	(0.18)	(−1.97)	(0.78)	(0.13)
Idiosyncratic	0.438***	0.230***	−0.0621	0.511***	0.271***	−0.132	0.514***	0.316***	−0.127
	(5.76)	(3.16)	(−0.67)	(5.74)	(3.04)	(−1.41)	(5.70)	(3.59)	(−1.29)
Duration of most shock	−0.220**	0.169*	0.344***	−0.223**	0.186*	0.329***	−0.199*	0.122	0.408***
	(−2.48)	(1.95)	(3.21)	(−2.17)	(1.87)	(3.09)	(−1.89)	(1.29)	(3.82)
Constant	−1.040**	−2.131***	−2.090***	−0.872	−2.607***	−1.687**	−0.909*	−2.521***	−1.873***
	(−2.10)	(−3.77)	(−2.92)	(−1.61)	(−3.90)	(−2.44)	(−1.67)	(−3.90)	(−2.63)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Food security models	*CSI*			*HDDS*			*FCS*		
Savings	−16.42***			−0.557			−0.447**		
	(−4.69)			(−1.34)			(−2.02)		
Climate shock	−0.487			−0.559**			0.0249		
	(−0.19)			(−2.12)			(0.18)		
Savings × climate shock	0.873			0.571**			0.0976		
	(0.34)			(2.13)			(0.68)		
Asset depletion	25.55***			1.228***			0.534**		
	(6.14)			(2.59)			(2.20)		
Asset depletion × climate shock	−6.023*			0.871**			0.260		
	(−1.90)			(2.54)			(1.44)		
Social networks	−6.959			−1.803***			−0.544*		
	(−1.39)			(−2.92)			(−1.72)		
Social networks × climate shock	2.744			0.402			0.135		
	(0.98)			(1.41)			(0.87)		
Pest shock	−3.065			−0.145			−0.205*		
	(−1.38)			(−0.62)			(−1.67)		
Savings × pest shock	0.645			−0.0957			0.206*		
	(0.30)			(−0.41)			(1.66)		
Asset depletion × pest shock	−0.660			−0.791***			−0.138		
	(−0.28)			(−2.99)			(−0.99)		
Social networks × pest shock	9.612***			0.239			0.141		
	(3.75)			(0.89)			(0.97)		
Health shock	−0.0593			0.689***			−0.130		
	(−0.03)			(2.71)			(−0.99)		
Savings × health shock	0.611			−0.435*			0.194		
	(0.26)			(−1.69)			(1.43)		
Asset depletion × health shock	3.421			−0.361			0.314**		
	(1.28)			(−1.21)			(2.01)		

(*Continued*)

Table 5. Continued.

Variable	Multivariate probit with CSI model			Multivariate probit with HDDS model			Multivariate probit with FCS model		
Variable	Savings	Asset depletion	Social networks	Savings	Asset depletion	Social networks	Savings	Asset depletion	Social networks
Social networks × health shock	−5.474 (−1.46)			0.0417 (0.11)			−0.0424 (−0.20)		
Price shock	−5.150** (−2.10)			−0.267 (−1.06)			−0.165 (−1.24)		
Savings × price shock	5.267** (2.24)			0.125 (0.49)			0.347** (2.56)		
Asset depletion × price shock	1.096 (0.44)			0.256 (0.93)			0.102 (0.71)		
Social networks × price shock	6.161** (2.17)			−0.233 (−0.78)			−0.0793 (−0.49)		
Constant	23.73*** (3.13)			6.861*** (10.07)			2.556*** (7.05)		
Control variables	Yes			Yes			Yes		
Model diagnostics									
ln σ_4	22.436*** (92.96)			1.918*** (23.94)			1.0202 (1.04)		
ρ_{12}	−0.6043*** (−9.50)			−0.5720*** (−9.70)			−0.5625*** (−9.84)		
ρ_{13}	−0.1712*** (−3.34)			−0.1891*** (−3.46)			−0.1947*** (−3.36)		
ρ_{14}	0.6574*** (2.37)			0.1999* (0.35)			0.1596 (0.30)		
ρ_{23}	−0.2505*** (−3.14)			−0.2619*** (−3.34)			−0.2403*** (−3.10)		
ρ_{24}	0.8140*** (0.92)			−0.5221*** (−4.90)			−0.5896*** (−7.77)		
ρ_{34}	0.2276*** (1.78)			0.4241*** (1.54)			0.2934** (2.38)		
LR χ^2	573.96***			565.02***			590.49***		
N	1284			1284			1282		

Note: *t*-values in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

correlation of climate shocks with CSI (note that larger negative values reflect better food security) implies that households that choose to deplete their assets when facing climate shock show less adverse consumption responses such as reducing or skipping meals. Households that deplete assets when faced with health shocks are able to maintain or improve the diversity and frequency of the food consumed. Households that use savings when they experience price shocks also exhibit lower adverse food consumption habits. Overall, these results show that depleting assets under shock interactions helps households to moderate the incremental effects. This is a key point for households that aim at consumption smoothing and in difficult periods would rather deplete their assets to maintain consumption rather than disrupting their consumption patterns. On the other hand, using savings in case of a pest shock increases households' dietary diversity and food consumption frequency. The reason for savings use increasing food security under price and pest shocks is not immediately apparent from the cross-sectional data we use, but for semi-commercial farm households, higher prices for home produced goods often lead to positive income effects that benefit those with marketable surpluses.

The results indicate that the moderating effect of social networks on food security is generally missing. This finding contrasts one finding from Islam and Walkerden (2014), who reported that social networks enabled Bangladeshi households to cope with natural disaster shocks in the initial stages. Our results also support a second finding of the authors that a social network strategy is no longer effective as the effect of the shock intensifies. Similarly, Béné et al. (2016) found that social networks played virtually no role in fisher households' resilience in Ghana, Fiji, Sri Lanka and Vietnam.

5. Conclusions and implications

While smallholder farmers in developing countries face multiple shocks, researchers mostly consider these shocks in isolation. We analyse the relationship between coinciding shocks and coping strategy choices of farm households in northern Ghana using binary probit models and a recursive model that incorporates multivariate probit and linear regression models.

We find that multiple shocks interact and generate incremental effects that influence coping strategy choices. First, controlling for the nature and duration of shocks, we determine that the effects of single shocks can be cushioned using measures that do not place demand on assets, e.g. cash savings and social networks. With shock interactions, however, households choose asset depletion to cope and maintain or increase food consumption. This choice implies that in rural settings where multiple shocks may occur, external interventions are required to help manage the interactive effects of coinciding shocks in order for households to cope without depleting their productive assets. To achieve this, non-governmental organizations that operate in the region can modify their intervention packages and prioritize access to functioning markets, especially for labour, savings or insurance, and outputs as a part of their key objectives. The provision of micro insurance especially, can help protect assets by transferring risks and acting as a safety net, which encourages households to venture into higher returning activities (Janzen & Carter, 2013).

Second, the coping strategy chosen depends on which of the four specific shocks (climate, pest, health and price) interact. In our study, climate-health, climate-pest, climate-price and pest-health shock interactions were shown to be the main reasons for choosing asset depletion. Given the prevalence of climate and health challenges in the study area, for example the high mosquito prevalence that increases the likelihood of people contracting malaria, it is not surprising that Northern Ghana continues to report high food insecurity and poverty levels. Multiple shock interactions partly explain why chronic food insecurity and poverty exist in shock-prone rural economies since they often place hefty demands on asset depletion due to their incremental effects. While asset accumulation is crucial for the poor to rise out of chronic poverty (Barrett et al., 2016), multiple shocks make it difficult to accumulate sufficient assets to escape poverty (Adato et al., 2006; Carter & Barrett, 2006).

Third, asset depletion is found to moderate the effect of climate shocks on households' dietary diversity and to reduce the likelihood that households exhibit adverse consumption habits. Asset depletion is also found to cushion the effect of health shocks on the diversity and frequency of household food consumption. Similarly, savings help to moderate the effect of climate shocks on household dietary diversity and of price shocks on the diversity and frequency of food consumption. Social networks play no significant role in cushioning the effects of shocks on household food security in the study context.

Notes

1. If the percentage increase in output prices equals the reciprocal value of the percentage decrease in output quantity, the revenue generated from the household's marketed surplus remains unaffected. If the price increase exceeds the quantity decrease, the household revenue will increase.
2. In the data there is no information on ex ante coping strategies. However, these are partly reflected in some of the control variables, e.g. accumulated assets or savings.
3. We also estimate model (1) using the actual number of shocks reported by households in the original data. We find that the parameters have the same signs and statistical significance as the shock categories, except for asset depletion and labour deployment.
4. Joint estimation is done using Roodman's (2011) conditional mixed process (cmp) program in Stata.

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