Economic and poverty related associations of capsid attack on cocoa farmers, and the effectiveness of the Codapec policy in rural Ghana.

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Abstract

Ecological shocks such as capsid attack remain pervasive and pose serious yield and welfare related concerns to cocoa farmers in Ghana. In response to this threat, the government of Ghana through the Ghana Cocoa Board, introduced the Codapec policy, a government subsidy program aimed at supporting farmers in fighting pests such as capsid through mass spraying and other agronomic activities. Against this backdrop, quantifying the economic cost associated with capsid attack, and assessing the effectiveness of the Codapec policy represents an important and interesting contribution for policy makers and current agricultural research works. In this paper, we first analyze the effect of capsid along three dimensions: yield, income and poverty outcomes, exploiting the exogenous spread of the capsid pest. We then examine the effectiveness of the government Codapec policy, in particular to assess whether receiving the Codapec support exacerbates or cushions farmers against capsid attack in relation to the above stated lines of outcomes. We leverage on a secondary household survey from the Royal Tropical Institute (KIT), covering cocoa growing regions in Ghana. We find that capsid invasion is negatively associated with cocoa yield, cocoa income, and per-capita income. We also document that capsid attack is positively associated with poverty, by increasing the prevalence of poverty, poverty gap, and poverty severity. Our estimated effects remain robust across several specifications and omitted variables. Switching to the effectiveness of the Codapec policy, we provide evidence that farmers who receive Codapec tend to increase their yield and reduce their probability of falling below the poverty line. Taken together, our results suggest that the Codapec policy, already in place in rural Ghana, may be vital in increasing yield of cocoa farmers, and a plausible intervention to reduce poverty.

Keywords: Capsid, cocoa, Codapec policy, poverty, Ghana

1. Introduction

Pest attacks are very pervasive and poses major threats to agricultural production in sub-Saharan Africa (SSA) (Graziosi et al., 2020; Midega et al., 2016; Sileshi et al., 2019; Talwana et al., 2016; Zhang et al., 2018). Given that a great majority of rural households (about 82%) in SSA are employed in the agricultural sector (Dercon & Gollin, 2014; Food and Agriculture Organization of the United Nations. et al., 2018), the effects of these attacks are strongly felt by residents in the region as compared to the rest of the world (Beegle et al., 2016; IFC, 2019). At the same time, increasing agricultural production in sub-Saharan Africa (SSA) holds great prospects given growing limited land availability concerns in regions such as South Asia (Rhebergen et al., 2020).[1] Accordingly, policy goals such as within the United Nations (UN) sustainable development framework see tackling challenges facing agricultural productivity such as pest attack, translating into high agricultural production and income gains as a plausible pathway out of poverty and enhancing rural development for people in SSA, and a credible way to solve food security challenges at the global and local scales (Sileshi et al., 2019; World Bank, 2021).

In Ghana, cocoa production remains one of the leading cash crops and a major source of foreign revenue for the government (Boysen et al., 2023; GCB, 2022). At the same time, cocoa production presents a credible pathway to alleviating poverty for rural households through employment and income gains (Bymolt et al., 2018). However, like many other crops cultivated in the country, cocoa production is constraint by ecological shocks such as capsid invasion leading to low outputs and poor welfare of farmers (Asare et al., 2021; Kongor et al., 2018). Capsid attack reduces both the quality and quantity of cocoa beans produced, leading to welfare losses (Asare et al., 2018; Okoffo et al., 2016). In the bid to address the effects of ecological pests such capsid attack, the government of Ghana though the Ghana Cocoa Board introduced the Cocoa Diseases and Pests Control Program (CODAPEC), a strategic initiative geared towards managing and mitigating the impact of diseases and pests on cocoa plantations (Ghana Cocoa Board, 2014; World Bank, 2011). The Codapec program popularly called cocoa mass spraying has the objective of training farmers on cultural and chemical methods to combat

[1] Growing concerns of land availability in countries such as Malaysia and Indonesia have led to enhanced interest in production activities especially for cash crops like oil palm in West Africa due to availability of lands. Thus availability of land in West Africa makes intensification and enhancing agricultural production an ideal opportunity.

pests. Also, farmers receive support from trained local sprayers popularly known as Codapec spray gangs, during chemical spraying operations (World Bank, 2011). Despite the apparent and considerable threats posed by capsid invasion, little rigorous evidence quantifying the effects of capsid invasion on yield, and welfare of cocoa farmers exist. Also, important policy questions assessing whether the Codapec initiative has been effective in addressing the effects of pest attack has garnered little attention. Quantifying the economic cost associated with capsid attack, and assessing the effectiveness of the Codapec policy represents undoubtedly an important and interesting contribution for policy makers and current agricultural research works.

In this paper, we investigate the association of capsid attack on dimensions of farm performance and farmer welfare, coupled with the effectiveness of the Codapec policy. In particular, our paper analyzes the association of capsid invasion on cocoa yield, cocoa income, per-capital income. We then proceed to access the associations of capsid attack on income poverty, poverty gap, and poverty severity. Finally, we investigate whether receiving the Codapec support is associated with exacerbating or cushioning farmers against this ecological shock in relation to the above stated outcomes. We are fortunate to leverage on a comprehensive household survey covering all cocoa growing regions in rural Ghana. We argue that the spread of capsid can be considered random, thus there is less likelihood of self-selection between infected and uninfected households. Similar arguments have previously been raised by Tabe-Ojong (2022) in his estimation of the effect of Prosopis on non-cognitive skills such as self-efficacy and locus of control. However, concerns may be raised about potential endogeneity of receiving the codapaec support. This is addressed by instrumenting the Codapec support dummy with the community share of farmers who received this support. Our identification strategy builds on extant studies highlighting the effect of social networks and neighborhood effects on innovation and technology adoption (Cofré-Bravo et al., 2019; Kreft et al., 2023; Krishnan & Patnam, 2014; Maertens & Barrett, 2013). To ascertain these claims and proceed with the ideal estimation technique (that is OLS vs 2SLS, and LPM vs IV-probit), a Wald test of exogeneity is performed following Wooldridge (2002) to verify whether receiving codapaec support amidst capsid attack is endogenous or not.

Equipped with this comprehensive data, and using diverse estimation strategies, we document that capsid attack poses both economic and statistically significant association on yield and various economic outcomes. We find that capsid invasion is associated with a reduction in yield, cocoa income, and per-capita income. We also find that capsid attack is associated with increases in the probability of cocoa households falling below the poverty line, poverty gap, and poverty severity. This is fairly intuitive given that cocoa production provides a credible pathway for rural farmers out of poverty through employment and income gains. Thus, any ecological shock negatively associated with production may undoubtedly be associated with increase in poverty. In summary, our findings establish that capsid attack and farmer welfare are two intertwined issues. We also demonstrate that our estimated associations remain robust across several specifications (including community fixed effects) and omitted variables following the framework of Oster (2019). Switching to the effectiveness of the Codapec support policy, first we do not find evidence in our analysis to conclusively say that the interaction term of Codapec support and capsid infection is endogenous. We provide evidence that farmers who receive this support tend to be associated with increases in yield and reduction in their probability of falling below the poverty line.

The objective of our study is to provide evidence-based research on the economic associations of capsid and the effectiveness of the Codapec policy in rural Ghana. In doing so, our research makes several contributions and speaks to three strands of literature. First, our research contributes to growing literature on the adverse impacts of ecological shocks (Badii et al., 2015; Constantine et al., 2023; Donatelli et al., 2017; Tambo & Kirui, 2021b). Our paper is most closely related to that of Kassie et al. (2020) and Tambo et al. (2021a). Using data from Ethiopia, Kassie et al. (2020) show that Fall army worm (FAW) negatively affects maize yield and sales. Still in the case of FAW, Tambo et al. (2021a) show the pest attack significantly reduces household income and increases the probability of experiencing hunger among maize farmers in rural Zimbabwe. However, our paper expands the scope of previous research works to investigate the associations of capsid attack not only on income and farm performance measures, but on broader poverty outcomes. More specifically, our novel contribution stems from showing that beyond reducing farm performance and quality of cocoa farmers, ecological shocks such as capsid may also have the potential to push farmers below the poverty line, increase their poverty gap and severity. Regarding the literature on capsid attack, unlike previous research that investigate the association of capsid attack, adoption, and investment in farm practices (Aneani & Ofori-Frimpong, 2013; Okoffo et al., 2016), in our paper, we examine the economic and poverty-related associations of capsid attack. In this regard, our research provides novel evidence on the associated cost of capsid infection to cocoa farmers[2].

[2] We want to emphasize here that our estimates are strictly interpreted as associations, thus our results likely provide the income, yield loss associated with capsid attack.

Second, our results contribute to extant studies investigating the impact of control strategies and policies geared towards reducing the effects of ecological shocks (Houngbo et al., 2020; Kumela et al., 2019; Laizer et al., 2019; Matova et al., 2020; Muriithi et al., 2016; Pretty & Bharucha, 2015). For instance, our estimated results are in some respect closely related to recent work by Tambo et al. (2020). The authors show that plant clinics are associated with an increase in maize yield and a reduction in the probability of maize farmers falling below the poverty line in rural Zambia. However, given the difference in context, type of crop and control strategy, our research provides new and informative insights in a unique environment. Context matters in decision and policy making as findings from different production systems, interventions and agri-environmental schemes cannot be generalized (Finger & Möhring, 2022; Tabe-Ojong, 2023). Ghana presents an interesting case study, given the fact that cocoa production faces capsid attack, despite being a native zone for cocoa production. Also, as earlier stated, cocoa production remains a major source of livelihood and foreign exchange for farmers and the government respectively (GCB, 2022). From a policy perspective, understanding whether control strategies and policies are yielding the intended returns is crucial in decision making among policy makers. Also, studying the effectiveness of measures and policies geared towards tackling challenges of cocoa production provides credible evidence in support of developmental goals such as SDG1 (no poverty), and SDG2 (zero hunger).

Lastly, and perhaps related to the second, our study provides novel contextual evidence. To the best of our knowledge our study is one of the first to investigate the yield, income and poverty relationships of capsid attack, and the effectiveness of the Codapec policy in a native cocoa growing rural Ghana. Earlier studies in the Ghanaian context particularly focused on the ex-post assessment of perceptions, determinants, and constraints of participation in the Codapec policy (Arko, 2020; Awudzi et al., 2021), and the effects of capsid attack on the adoption of farm management practices (Aneani & Ofori-Frimpong, 2013; Okoffo et al., 2016). A notable exception is the recent study Asante et al. (2023) which explored the effects of mass spraying together with other agricultural technologies on cocoa yield, gross cocoa income, and per-capita consumption.

The rest of the paper proceeds as follows. In the next section, we provide the link between capsid attack, cocoa production and farmer welfare, a background on the Codapec policy, and finally derive some tentative hypothesis. Section 3 describes the study context, data and variables used in our analysis. Section 4 briefly provides descriptive statistics of our variables used in our analysis. Section 5 describes our empirical strategy. We proceed to discuss our results in section 6, and finally conclude in the last section.

2. Background and conceptualization

In what follows, we provide a brief background on capsid attack, and conceptual considerations on how capsid attack could potentially affect yield and welfare outcomes of cocoa farmers in rural Ghana. Finally, we discuss how the Codapec policy could mitigate the threats of capsid attack. While little evidence on how the Codapec policy affects welfare outcomes exists, we build on previous empirical and theoretical findings of similar control strategies and policies in other contexts.

2.1 Capsid attack, cocoa production, and welfare

The name *Capsid* commonly refers to species of insects under the family *Miridae*, formerly known as *Capsidae* due to their capsule or box-like shape. Capsids are roughly 5-6mm in length, with a characteristic piercing-sucking mouthpart and relatively large antennae (Gratwick, 1992). Many species of *Miridae* are notorious pests, owing to their threats posed to many cash crops such as cotton, coffee, and cocoa. Capsids are also known for transmitting plant diseases, causing further damage to agricultural yields (Brun et al., 1997; Gratwick, 1992). In Ghana, several species of capsid exist namely: *Distantiella Theobroma*, *Sahlbergella Singularis Haglund*, *Helopeltis Theobroma*/*Antonii* (Awudzi et al., 2021; Dormon et al., 2007). The spread of capsid pests is often facilitated by their ability to travel long distances, aided by wind currents or through transportation of infested plant material (Leston, 1973). Also, the climatic conditions of Ghana and West Africa play a crucial role in facilitating the spread of capsid pests. These conditions include warm temperatures, high humidity levels, and the availability of suitable host plants. Since the cocoa plant, *Theobroma Cacao* thrives in similar climatic conditions, species of Capsids have evolved as oligophagous and have found cocoa plantations as their host (Awudzi et al., 2021; Dormon et al., 2007).

The effects of Capsid pests on cocoa production are multifaceted: affecting both yield and the overall quality[3] of the cocoa harvested. The pests primarily target the developing pods, feeding on various parts such as buds, flowers, and new growth (Ayenor et al., 2007). The feeding activity provokes distortion and malformation of the pods, as well as lesions, which can be

[3] Given the nature of our data, we are not able to assess the relationship between capsid attack and quality of cocoa beans.

exploited by fungal infections that can even cause the plant to wilt and die (Brun et al., 1997). These often cause the reduction of the quantity of cocoa produced by hindering pod development, and also significantly impacting the quality of the cocoa beans. Pods affected by capsid feeding often exhibit discoloration and compromised structural integrity, resulting in a lower market value for the harvested beans (Awudzi et al., 2021; Gratwick, 1992). The quantity of cocoa produced is directly influenced by the extent of capsid infestations, as the pests' feeding activities can lead to premature dropping of pods and decreased overall yield. A study by Ayenor et al. (2007) shows that cocoa plant losses reach up to 70%, while the yield of cocoa may be reduced by up to 30% in the most severe infestations. Additionally, Capsid bugs are known vectors of plant diseases such as the fungal *Phytophthora 'Pod Rot'* and C*eratocystis Wilt*, the bacterial *Witches Broom Disease*, and viral conditions such as *Vascular Streak Dieback* and *Cacao Swollen Shoot Virus,* all of which further contribute to the decline in cocoa quantity and quality (Lass & Wood, 1985).

From the above, capsid attack can have immense yield, and potentially income and poverty effects on smallholder. The reduction in quantity and quality of cocoa beans means a reduction in revenue from cocoa sales, and thus total income (Asare et al., 2018; Okoffo et al., 2016). The extent to which the income and quality of life of cocoa farmers are affected depends on the reliance of the farmer on his on-farm activities (Asare et al., 2018). If the farmer's income stream is solely reliant upon cocoa production, then the impact of capsid bugs may in theory wipe out a major part of their total income. Given the labor and capital intense nature of cocoa production, most farmers invest a significant part of their income in cocoa production, and in turn, depend hugely on cocoa production for a significant part of their income (Löwe, 2017; Scudder et al., 2022). Also, the study by Asamoah et al. (2013) shows that on average cocoa income constitutes more than 70% of household total income in some parts of rural Ghana. Based on this, capsid invasion may not only lead to cocoa income losses but also loss in total and per-capita income.

To most cocoa farmers, cocoa production is not only a source of employment, but a plausible way out of the poverty trap (Bymolt et al., 2018). Severe pest attacks can act as a shock to household income and can initiate a downward spiral into poverty (Lenné, 2000). If the shock to household income is sufficient, the farmer will fall into poverty and will see standards of living fall. This is because 'crop failure due to pests will reduce both the availability of and direct entitlement to food for the poor' (Lenné, 2000). Reduced yield due to pest attack could lead to low disposable income available to be spent on food purchase or for investment (Tambo et al., 2020). The effect may tend to compound over time since cocoa trees may wilt and die, and without capital for preventative measures, capsids will strike in the following year, and yields will fall even lower, once again lowering income, which could lead to reduction and worsening the severity of poverty. The lesser capacity of smallholder farmers to cope with, and prevent, capsid infestations will mean that the poorest farmers see the largest reduction in yields over time, meaning the depth of poverty is likely to increase. Likewise, poverty will become more severe as the downward spiral takes effect.

2.2 Codapec Program

Given that most cocoa farms in Ghana report the attack of capsids (Kongor et al., 2018), pest management is crucial to mitigate their vast risks. The Codapec policy, fully known as the Cocoa Diseases and Pests Control Program, is a strategic initiative aimed at managing and mitigating the impact of diseases and pests on cocoa plantations in Ghana. The policy was first introduced in 2001 by Ghana Cocoa Board (COCOBOD), as a response to the escalating challenges posed by various cocoa diseases and pests (Ghana Cocoa Board, 2014; World Bank, 2011)..

Codapec's primary activity is crop spraying, whereby farms are sprayed with insecticides and fungicides twice annually and at zero cost to the farmer. Further activities encompassed by the Codapec policy include training and education on pesticide use; farmers are encouraged to implement good practices such as pruning and sanitation to minimize the breeding grounds for pests and pathogens (Anang et al., 2013). One noteworthy aspect of the Codapec policy is its emphasis on community engagement and the formation of farmer task force. Through collaborative efforts, the policy seeks to create a network of informed and empowered farmers who actively participate in disease and pest management programs. This community-based approach fosters knowledge-sharing and the adoption of best practices, contributing to the overall resilience of Ghana's cocoa industry.

2.3 Hypothesis

Following the above background and conceptualization, we formulate the following tentative hypotheses.

Hypothesis 1: Capsid attacks reduce yield and income.

Hypothesis 2: Capsid attacks increase poverty.

Hypothesis 3: Receiving Codapec support in the midst of capsid attacks increases yield and reduces poverty.

3. Study context, data source, and measurement of variables

Ghana is divided into five distinctive climatic zones namely: Guinea and Sudan Savanna zones, covering the Northern parts of the country, the Transition, Forest zones which spread across the middle belts of Ghana, and the Coastal zone which spans the Southern part of the country (Yamba et al., 2023). The diversity in zones makes it conducive for different types of crops to be grown as the zones are characterized by different climatic conditions (Bessah et al., 2022).

Cocoa production occurs predominantly in the Forest zones, where temperature is relatively low and annual rainfall is high[4] (Ameyaw et al., 2018). The cocoa production cycle starts with planting of saplings often in plantation style. After about 5 years, the tree starts to bear fruit, and after careful pruning, weeding, and crop protection, the main harvest occurs from October onwards (Cocoa Research Institute et al., 2017). The cocoa pods are mostly processed on the farm, where the beans are separated from the pod, fermented and dried for about two weeks. All processed beans are then sold to COCOBOD's subsidiary the Cocoa Marketing Company (CMC), a government institution which buys at fixed prices before exporting abroad[5] (Cocoa Research Institute et al., 2017). Cocoa production is an essential part of the Ghanaian economy, contributing up to 25% of total exports (Abbadi et al., 2019), and being worth over $2bn in export value (COCOBOD, 2023). Globally, Ghana ranked the 2nd largest producer of cocoa behind Ivory Coast, with a 16.3% market share of cocoa beans produced in 2020 (Bermudez et al., 2022; Boysen et al., 2023).

More than 800,000 smallholder farmers are involved in cocoa production in Ghana, (COCOBOD, 2023). Also, Amponsah-Doku et al. (2022) show that about 1.5 million hectares of land are used in cocoa production, with an annual production of about 850,000 metric tonnes of cocoa beans (COCOBOD, 2023). Aside farmers owning their lands, major land tenure systems in cocoa production include: *abusa* and a*bunu*. Both are forms of sharecropping: whereas, in the abusa system, the abusa tenant takes two thirds of the harvest, the abunu tenant splits the proceeds equally with the landowner (Cocoa Research Institute et al., 2017).

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[4] It is noteworthy to state that the forest zones are characterised by Bi modal rainfall patterns. The major rainy season lasts from March to July, while the minor rainy season starts from September to October.

[5] Licensed Buying Companies (LBCs) also purchase on behalf of the CBC.

For our empirical analysis, we rely on household survey data from the Royal Tropical Institute (KIT) for the project *"Demystifying the cocoa sector in Ghana"* (Bymolt et al., 2018). The cross-sectional data captures detailed information on household socioeconomic factors, crop diversification and crop choices, income sources, food security and nutrition indicators from 5 cocoa-growing regions in Ghana. Thus, the data provides variables that can be used to provide meaningful snapshots of cocoa farmer welfare in Ghana. The over-arching goal of this project by KIT is to contribute towards evidence-based research on various aspects of cocoa production in Ghana (Bymolt et al., 2018). The household survey was collected between November 2016 and January 2017 in 5 regions namely: Ashanti, Western, Brong-Ahafo, Central, and Eastern using a multi-stage sampling technique. The data collection directly preceded the main harvest period making it ideal to collect vital production information and reduce recall errors. In the first stage, 29 districts were selected from the 5 regions, with more weight given to the Western Region[6], then a total of 37 communities were selected from each district in the second stage. Overall, 1,560 random farmers from each community were selected and interviewed, with enumerators conducting the interviews in their local language. Additionally, 37 focus group discussions were conducted in each community in locations[7] selected by the community. The enumerators and facilitators received a 3-day intensive training from KIT to familiarize them with the research and the use of tablets for the data collection. Also, a KIT advisor checked every completed household survey for any errors in the first 10 days of data collection.

In this paper, we restrict our analysis to only cocoa growing households[8] as they are usually affected by capsid. We confirm this from our data, and further establish that no non-cocoa household received the Codapec support. We use the answer to the question "Did your household experience capsid attack (akate) on your cocoa farm", to elicit whether the household experienced capsid attack[9]. Another section of the survey instruments specifically collected data on various cocoa activities and government support programs. From here, we generate the Codapec support variable which equals one if the cocoa household received the Codapec government support or 0, if otherwise.

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[6] Western region was given more weight because the region produced about 53% of the country's total production.
[7] For instance, most focus group discussions were conducted in local churches or community centres.
[8] Though the theme of the research was on cocoa production, additional 304, non-cocoa growing households were interviewed. We therefore drop these observations from our analysis. Finally, after careful data cleaning and dropping of missing observations, our final estimation sample was reduced to 990 observations.
[9] In terms of awareness, research by in the Ashanti and Eastern regions show that about 87% of the sampled farmers had great knowledge of the capsid pest and perceived it to be the most economically important pest of cocoa. Also given the prevalence of the pest in Ghana, we have little reason to believe that most farmers were not aware of the capsid pest.

Outcome variables

In our empirical analysis, we explore three dimensions. The first dimension is to assess the relationship of capsid on output related outcome, coupled with the effectiveness of the Codapec policy in cushioning cocoa farmers against capsid attack (yield cushioning associations). The second and third dimensions involve analyzing the effect of capsid and the Codapec support on income and poverty indicators. Our first outcome variable (output related outcome) is yield which is measured in kilogram per hectare.

The income variables are per-capita income and gross income from cocoa all measured in US dollars. We generate per-capita income by dividing total income by the household size, while the gross cocoa income measures the total value of all cocoa sold by the household. The first poverty indicator is income poverty and is a dummy variable which takes the value of 1 if the cocoa households' daily per-capita income falls below the international line of 1.90 dollars per day. Beyond the income poverty variable, we are also interested in how far on average cocoa households fall below the poverty line. We generate a poverty gap variable by subtracting the daily per-capita income from the international poverty line (1.90 dollars) and dividing by 1.90 dollars. To ensure that our poverty gap range between 0 and 1, we follow recent work by (Tabe-Ojong & Dureti, 2023), and replace negative values with zeros. Lastly, we generate poverty severity, which we compute by squaring the poverty gap. This indicator helps us to access the severity of poverty among poor cocoa households (Liverpool-Tasie et al., 2023).

4. Descriptive statistics

We present the descriptive statistics of our variables of interest, outcome, and control variables in this section. In the sampled households, the incidence of capsid is reported by 52% of cocoa farmers. However, we find that only about 14% of the sampled farmers received Codapec support. The average household size is about 6 members, while the average age of household head in the sample is about 52 years. On average, about 85% of the household heads in our sample are males, with about 16% of the household heads attaining at least secondary education. Considering the size of lands, the average size of landholdings was about 3.7 hectares, while about 2.8 hectares of the landholdings was assigned to cocoa production. On average, farmers in our sample travel about 42 km to the nearest input dealer, while travelling about 55 km to their main farm. In terms of plot investment, we find that only 5% of our sampled farmers applied manure, while the weeding frequency is about 2 times on average.

Also, we find that on average, 106kg/ha of fertilizer is applied by cocoa farmers, with almost 80% of the farmers intercropping cocoa with other crops.

Switching to the outcome variables, the mean annual cocoa income is approximately US$ 1760, while averagely the per-capita income is approximately US$ 603. On average the mean yield in our sample is approximately 404 kg/ha. We find that on average about 65% of our sampled households live below the poverty line, with an average poverty gap of about 39% and a poverty severity of about 36%. Looking at the mean difference in outcome variables by capsid attack (Appendix), we find economic and statistically significant differences between households who reported capsid attack and households who did not. Farmers who reported capsid attack tend to have lower yields, cocoa income, and per-capita income than their counterparts who did not report capsid attack. Conversely, capsid infected households have a higher probability of falling below the poverty line, higher poverty gap, and experience higher poverty severity than households who did not report capsid attack. Although these statistics provide a brief impression of our data and to some extent the economic effects of capsid attacks, these analyses are unconditional. Given that we do not control for any confounding factors, caution should be taken in drawing any conclusions. We conduct regression analysis in section 5, conditioning the effects of capsid attack on other covariates.

Table 1: Descriptive statistics

Variables	Mean	Standard deviation
Outcome variables		
Yield (Kg/ha)[10]	439.917	266.888
Cocoa income (US$)	1756.372	1910.339
Per-capita income (US$)	602.604	872.837
Income poverty (1/0)	0.648	0.477
Poverty gap (0-1)	0.391	0.328
Poverty severity (0-1)	0.260	0.273
Variables of interest		
Capsid attack (1/0)	0.515	0.500

[10] It is noteworthy that since cocoa is a cash crop all households produced predominately to sell. In our dataset there was significantly no difference between yield and quantity sold (Though households were asked to report both values). Thus, cocoa yield can also be seen as the quantity of cocoa sold per hectare.

Codapec support (1/0)	0.138	0.345
Control variables		
Household size (number)	5.878	2.640
Age of household head (years)	51.523	13.397
Gender of household head (1 = male)	0.847	0.360
Educational level of household head (1= at least completed secondary school)	0.162	0.368
Access to credit (1 = yes)	0.267	0.442
Land holding (hectares)	3.693	3.489
Cocoa area (hectares)	2.792	2.317
Distance to main farm (km)[11]	54.982	41.529
Distance to input dealer (km)	41.583	47.284
Producer group membership (1= yes)	0.102	0.303
Weeding frequency	2.144	0.985
Manure (1 = yes)	0.050	0.219
Quantity of fertilizer (kg/ha)	105.914	173.778
Cocoa intercropping[12] (1 = yes)	0.797	0.402
Observations	990	

5. Empirical strategy

Our analysis assumes and exploits the quasi-random variations in the spread of capsid in cocoa growing regions in Ghana. In other words, we assume that the spread of capsid can be considered as an exogenous shock. Given this assumption, we estimate the effects of capsid attack on our key outcome variables employing the following econometric functional form:

$$\boldsymbol{Y_i = \beta_0 + \beta_1 Capsid_i + \beta_2 X_i + V_v} + \mu_i \qquad \textbf{(1)}$$

Where the dependent variable $\boldsymbol{Y}$ represents our outcome variables (yield, cocoa income, per-capita income, income poverty, poverty gap, and poverty severity) for cocoa farmer *i*. Capsid denotes the capsid dummy variable which takes the value of 1 if the cocoa household experienced capsid shock and 0 if otherwise. $\boldsymbol{X_i}$ captures household characteristics and vector

[11] In most cocoa growing areas in Ghana, main farms are usually located far from household residence. Cocoa farmers usually make small huts in the farms, where they sleep and spend extended periods during intensive cropping activities, like harvesting, drying of cocoa beans.
[12] In our sample, the major crops intercropped with cocoa were cocoyam and cassava.

of relevant covariates. We include community fixed effects (V_v), following recent works of Liverpool-Tasie et al. (2023) and Kassie et al. (2020) to control for time invariant community features that differ across communities. These features include agro-ecological, agroclimatic, and economic features which may concurrently influence the spread of capsid and other welfare measures. Again, the inclusion of community fixed effects implies that our variable of interest is exclusively identified from within-community variations (Andersen et al., 2022). Lastly, μ_i represents the stochastic error term. The equation conceptually relates to scenarios: dichotomous invasion of capsid on the right-hand side and increase or decrease in diverse outcome variables on the left-hand side. Our key parameter of interest, $\boldsymbol{\beta_1}$, captures the effect of capsid attack on our outcome variables. Here, we hypothesize differing relationships depending on the outcome variable in question. In particular, we hypothesize a negative relationship between capsid, yield, and income variables, thus a negative sign of $\boldsymbol{\beta_1}$. Regarding our poverty outcomes, capsid attack may likely worsen the poverty status of our sampled cocoa farmers, thus we hypothesize a positive relationship, meaning a positive sign of $\boldsymbol{\beta_1}$.

Considering the different nature of our dependent variables, we estimate an Ordinary Least Square regressions (OLS) for our continuous outcome variables. We estimate a Linear Probability Model (LPM), following Angrist & Pischke (2009) for our dummy income poverty dependent variable. The coefficients of the LPM are straightforward to interpret and has the advantage of avoiding identification by functional form which is usually associated with other models (Angrist & Pischke, 2009). Our choice of covariates is motivated by literature on ecological shocks, non-cognitive skills, and household welfare (Bariw et al., 2020; Kalyebi et al., 2023; Kassie et al., 2020; Tabe-Ojong, 2022; Tambo et al., 2021). We control for household characteristics such as age, gender, and educational level of household head, producer group membership. We also include land and cocoa land holdings to capture indicators of asset endowment. Further control variables include distance to main farm and input dealers to capture diverse transactional cost indicators. We also include in our model plot investment variables such as weeding frequency, dummy for cocoa intercropping, manure use and fertilizer usage.

In our next objective, we assess the effectiveness of the Codapec support in cushioning farmers against this ecological shock and improving farming and welfare outcomes. To do so, we introduce a dummy variable *S*, which takes the value of 1 if the farmer received the Codapec support or 0 if otherwise. We proceed to estimate an augmented version of equation 1 using the following regression:

$$\boldsymbol{Y_i} = \boldsymbol{\beta_0}+\boldsymbol{\beta_1 Capsid_i}+\boldsymbol{\beta_2 X_i} + \boldsymbol{\beta_3 S_i} + \boldsymbol{\beta_4}(\boldsymbol{Capsid_i} * \boldsymbol{S_i})+\boldsymbol{V_v} + \mu_{\boldsymbol{i}} \qquad \textbf{(2)}$$

To explicitly estimate the effect of receiving Codapec support on our above discussed outcome variable, we interact the Codapec dummy with the capsid attack dummy. Here, our parameter of interest, $\boldsymbol{\beta_4}$**,** expresses whether the Codapec support exacerbates sensitivity to a capsid shock ($\boldsymbol{\beta_4 < 0}$) or mitigates the capsid shock ($\boldsymbol{\beta_4 > 0}$) in terms of yield effects. Regarding poverty outcomes we expect $\boldsymbol{\beta_4 < 0}$ if the Codapec support helps cocoa farmers reduce their poverty or $\boldsymbol{\beta_4 > 0}$ if otherwise. In summary, we hypothesize a positive $\boldsymbol{\beta_4}$ for yield and other income measures, and a negative $\boldsymbol{\beta_4}$ for poverty measures.

Though we assume a random spread of capsid, we cannot conclusively say the decision to receive the Codapec support is random. This is because the Codapec variable may likely be endogenous, suggesting that we may face what Bia et al. (2023) describe as the 'double selection problem'. For instance, certain unobserved factors such as farmers motivation, intelligence or social status may likely influence farmers access to Codapec support, and concurrently comove their income and poverty status (unobserved heterogeneity). Again, a farmer may receive Codapec support because the farmer has higher yield or income levels, or conversely, receiving Codapec support may increase the yield, income and reduce the poverty levels of farmers (reverse causality). Given the difficulty in claiming accuracy of the data generating process, another source of endogeneity concerns may be measurement error. However, since the data was collected by well-trained enumerators, we are likely to face issues with our variables of interest.

To reduce issues of endogeneity due to reverse causality and unobserved heterogeneity, we use an instrumental variable approach. As emphasized by Tabe-Ojong et al. (2023), obtaining a reliable and theoretical sound household level instrument in a non-experiment research is not easy. The instrument must satisfy both the relevant and exclusion criteria that is, the instrument must be correlated with the potential endogenous variable (Codapec support dummy), but not correlated with the error term in the structural equation (equation 1), conditioned on the relevant controls. In our studies, we propose the community Codapec support rate as a valid instrument for our dummy Codapec support variable (For examples of studies that used similar instrument please see: (Geffersa & Tabe-Ojong, 2023; Kang et al., 2023; Tabe Ojong et al., 2022). The use of this instrument is informed by burgeoning studies highlighting the importance of social networks and neighbours in policy and technology adoption (Cofré-Bravo et al., 2019; Kreft et al., 2023; Krishnan & Patnam, 2014; Maertens & Barrett, 2013). We generate this variable by counting the number of farmers who received Codapec support in the community (excluding the household under consideration), and then dividing by the total number of farmers in the community. We argue that the higher the community Codapec support rate, the higher the likelihood of the farmer to receive the Codapec support. The community rate may serve as a proxy for information flow and sharing which is vital for any innovation, and technology adoption (Tabe-Ojong et al., 2023). Thus, it is likely that cocoa farmers surrounded by their peers who have received the Codapec support would likely learn about the benefits of the policy, and also receive the support, due to social learning and neighbourhood effects. Regarding the exclusion criterion, we argue that since we generated our instruments at a higher geographical level (community level), with the reference household excluded, household omitted variables in the structural equation, may be less likely to correlate with the Codapec support community ratio, unless through the Codapec support dummy. Also, we perform a falsification test proposed by Di Falco et al. (2011) to ascertain this argument. This test hinges on the assumption that the admissibility of the instrument is established if the instrument correlates with the potential endogenous variable (Codapec dummy) but does not affect the outcome of the non-treated cocoa farmers (farmers who did not receive the Codapec support) (Di Falco et al., 2011; Falco & Veronesi, 2013).

We estimate the first stage reduced form regression as specified below:

$$\boldsymbol{S_i = \gamma_0 + \gamma_1 Capsid_i + \gamma_2 X_i + \gamma_3 T_i + V_v + \varepsilon_i} \qquad \textbf{(3)}$$

Where $\boldsymbol{T_i}$ is the community Codapec support rate. Again, considering the nature of our dependent variables, we estimate two forms of instrumental variable regressions. With our continuous outcome variables, we run a normal two stage least square (2SLS) regression. We estimate an IV-probit regression in the spirit of a control function approach for the income poverty dummy (Smith & Blundell, 1986). The IV-probit regression involves a two-stage residual inclusion process, where we run the first stage regression and use the residuals values instead of the fitted values used in the 2SLS for the second stage endogeneity correction process. The IV-probit model produces consistent estimates in the presence of dummy outcome variables (Abdulai et al., 2011; Wossen et al., 2015).

The interaction term, $Capsid_i * S_i$ may be endogenous for which we instrument with the interaction term $Capsid_i * T_i$. We estimate another first stage reduced form regression by a similar token using the following econometric approach:

$$\boldsymbol{Capsid_i * S_i = \alpha_0 + \alpha_1 Capsid_i + \alpha_2(Capsid_i * T_i) + \alpha_3 X_i + V_v + \varepsilon_i} \quad \textbf{(4)}$$

From the IV-probit regression, we estimate the Wald test of exogeneity (Wooldridge, 2002), to ascertain if indeed the interaction term $Capsid_i * S_i$ is endogenous before deciding whether it is appropriate to use the OLS and LPM model or the 2SLS and IV-probit regressions. In light of these considerations, we make inferences strictly as associations, thus our estimates are interpreted as correlations.

6. Results and discussion

6.1 Capsid Attack, yield, and income

We begin by discussing the relationship between capsid attack, cocoa yield, per-capita income, and cocoa income as presented in table 2. The results show that capsid attack is negatively associated with yield and all income measures. Again, we find very similar and consistent signs and sizes of the estimated coefficients across different model specifications. These results provide evidence in support of the yield and income reducing hypothesis formulated in chapter 2. We transform the quantities of cocoa yield into logarithm scale[13], thus our interpretations are in percentages. Particularly, after controlling for community fixed effects and other factors that influence cocoa yield, our result follows intuitively: experiencing capsid attack is associated with a 9.4 percentage points reduction in cocoa yield. The negative relationship between capsid attack and yield is expected given the far-reaching effects caused by capsid feeding on cocoa pods as discussed earlier, hindering pod development, and the transmission of fungal diseases, causing the cocoa plant to wilt and die (Ayenor et al., 2007). Our results lend credence to earlier works of Cerda et al. (2017) and Constantine et al. (2023) who also found yield reducing effects of ecological shocks such as apple snail.

Considering the income effects of capsid attack, we present results on the association between capsid attack, per-capita income, and cocoa income. Here we find that capsid shock is associated with a reduction in per-capita income by approximately 73 US$. Surprisingly, we find a statistically insignificant relationship between capsid attack and cocoa income, though our results show a strong negative economic effect[14] of capsid attack on cocoa income. Thus far, our results suggest that ecological shocks such capsid do not only have yield reducing effects but also associated with the reduction in quality and standards of cocoa households. The negative associations of capsid shocks and different proxies of farmer income are consistent and corroborate with results of earlier works (Kassie et al., 2020; Tambo et al., 2021), which document similar income reducing effect of fall army worm in developing countries.

[13] Given that cocoa is a cash crop in rural Ghana, all cocoa growing households primarily cultivate cocoa for commercialization purposes. Thus, using an inverse hyperbolic sine (IHS) transformation as used in earlier works of (Kassie et al., 2020), in instances where some farmers have zero values was not appropriate in our case.

[14] We discuss both the economic and statistical effects capsid attack may have on the key outcomes. This follows recent scholarly literature regarding the p-value debate and the need to discuss considerable effects of coefficients even if they are statistically insignificant. See Heckelei et al. (2021) and Verbeek (2017) for further discussion on statistical versus economic effects.

Table 2: Estimates of Capsid attack, yield, and income

Variable	In (yield, kg/ha)		Per-capita income (US$)		Cocoa income (US$)	
	(1)	(2)	(1)	(2)	(1)	(2)
Capsid attack (1/0)	-0.104**	-0.094**	-97.829*	-73.305*	-177.603	-134.062
	(0.041)	(0.039)	(53.632)	(42.722)	(118.513)	(91.056)
Other controls	No	Yes	No	Yes	No	Yes
R squared	0.162	0.284	0.069	0.401	0.121	0.533
Observations	990	990	990	990	990	990

Notes: Other controls include household size, age, gender and educational level of household head, land tenure, access to credit, distance to source of input, membership of producer group, size of cocoa farm, weeding frequency, distance to main plot of land for cocoa farming, cocoa intercropped, quantity of manure used, quantity of fertilizer used. We include community fixed effects in all specifications. Robust standard errors are reported in parenthesis. *** p<0.01, ** p<0.05, * p< 0.1. We report full results in the appendix.

6.2 Capsid Attack and poverty outcomes

Having shown the yield and income reducing associations of a capsid attack, we explore whether capsid attack is also associated with household poverty. We present the results of the association between a capsid shock, income poverty, poverty gap and poverty severity in table 3. We hypothesize that given the fact that cocoa production presents a credible pathway out of poverty for rural cocoa farmers, capsid attack is likely to push farmers below the poverty line. Our estimated results provide evidence in support of our hypothesis suggesting that cocoa households experiencing capsid invasion are 10% more likely to move below the poverty line ($1.90 a day). Moreover, experiencing capsid attack is associated with an increase in poverty gap by approximately 5% while further increasing poverty severity by about 4%. Our estimates imply that capsid attack not only associated with increases in the level of poverty, but also widens the gap of cocoa farmers in reaching the $1.90 poverty line. Overall, our findings suggest that the negative yield and income associations of capsid may further push cocoa farmers below the poverty line and exacerbates the status by deepening their poverty gap and severity.

Taken our results together, the consistent positive association of capsid shock and different proxies of farmer welfare and poverty indicators affirms the commonly held view that ecological shocks have far-reaching effects on the welfare of farmers especially in SSA, thus control strategies geared at reducing the effects of pest attack are essential to increase the welfare of rural poor farmers and achieve poverty reduction (Barzman et al., 2015; Heeb et al., 2019; Pretty & Bharucha, 2015b; Tambo & Kirui, 2021).

Table 3: Estimates of Capsid attack, and poverty outcomes

Variable	Income poverty (dummy)		Poverty gap		Poverty severity	
	(1)	(2)	(1)	(2)	(1)	(2)
Capsid attack (1/0)	0.104***	0.101***	0.056 **	0.049**	0.045**	0.040**
	(0.029)	(0.026)	(0.021)	(0.016)	(0.017)	(0.014)
Other controls	No	Yes	No	Yes	No	Yes
R squared	0.072	0.406	0.098	0.476	0.100	0.444
Observations	990	990	990	990	990	990

Notes: Other controls include household size, age, gender and educational level of household head, land tenure, access to credit, distance to source of input, membership of producer group, size of cocoa farm, weeding frequency, distance to main plot of land for cocoa farming, cocoa intercropped, quantity of manure used, quantity of fertilizer used. We include community fixed effects in all specifications. Robust standard errors are reported in parenthesis. *** p<0.01, ** p<0.05, * p< 0.1. We use an LPM to estimate the income poverty relationship. We report full results in the appendix.

6.3 Oster bound test for unobserved heterogeneity and coefficient stability.

In this sub-section, we conduct a battery of robustness checks to assess the stability of our estimated coefficients to omitted variables. Despite consistent and reassuringly steady estimates to a systematical stepwise regression, our results may be affected by unobserved variables in the error term. We proceed with the Oster bounds test proposed by Oster (2019) to evaluate how much unobserved variables should be to nullify the statistical effect of capsid attack. Again, this test quantifies how much our capsid estimates will change if selection on observations equals selection on unobervables. The Oster bound test hinges on the assumption that the relationship between capsid attack (variable of interest) and observables (control variables) provides information on recovering the relationship between capsid attack and unobservables (Tabe-Ojong, 2022).

We start by computing the delta value of cocoa yield using an R^2 value of 0.369 (1.3 times the R^2 of our OLS as suggested by Oster 2019). The value of approximately 27 suggest that the unobervables in the error term must be 27 times as much as the rich control variables in our OLS in order to cancel out the statistically significant capsid coefficient. Also, the beta value of -0.092 suggest that with equal number of observables and unobervables, our capsid estimate will shrink from -0.094 (in our OLS) to -0.092. This reaffirms the stability of our estimated coefficient to selection on unobservables. Switching to per-capita income, similarly we find strong stability with our estimated coefficients. With equal number of selection of observables and selection on unobervables our estimated coefficient will change from -73.305 to -73.050. For our statistically significant estimate of per-capita income to be completely nullified, omitted variables should be 34 times the control variables in our OLS model. Finally with our income-poverty variable, the delta value suggests that selection on unobervables will need to be 63 times the rich control variables, to cancel out the statistical significance of our estimated coefficient.

Table 4: Oster bound test

Variable	In (yield, kg/ha)		Per-capita income		Income poverty	
	(1)	(2)	(1)	(2)	(1)	(2)
Beta	0	-0.092	0	-73.050	0	0.049
Delta	27.034	1	34.096	1	63.478	1
R^2 max	0.369	0.369	0.521	0.521	0.618	0.618

6.4 Effectiveness of the Codapec support policy

Before proceeding to discuss, the effectiveness of the policy support in reducing yield losses and poverty outcomes due to capsid attack, we comment on the validity checks of our instrument from the first stage. As discussed in chapter 5, we estimate a 2SLS regression for the continuous outcome variables, and an IV-probit in the spirit of a control function approach for the dummy income poverty variable. In terms of the relevance of our instrument, the community share of farmers who received Codapec support is positively correlated with access to Codapec support. Our results show that the higher the share of farmers with Codapec support in the community (excluding the household under consideration), the higher the probability of receiving the Codapec support. This is fairly intuitive, given that a larger share connotes higher number of farmers' neighbours who received, and know more about the merits of the policy support. These neighbours are in a better position to relay such information to their fellow farmers, influencing their decisions to participate and receive the Codapec support. We proceed to investigate the strength of the instrument. The F-statistics further confirms the relevance of our instrument and rules out any concerns of asymptotic bias from weak instruments (Knippenberg et al., 2020). We confirm this finding by comparing our F-statistic (53.957) to the rule of thumb value of 10 highlighted by (Staiger & Stock, 1997). Our F-statistic value above 10 signifies that our instrument is sufficiently strong (see Table 5).

To test the exclusion criterion of our identification strategy, we perform a falsification test by running the same regression of our instrument and relevant controls on our outcome variables using a sub-sample of farmers who did not receive the Codapec support. Our results showed no statistically significant relationship between the community share of farmers who received Codapec support and yield, income and poverty outcomes of farmers who received did not receive Codapec support. Finally, we estimate the Wald test of exogeneity to ascertain if the interaction term of dummy Codapec support and capsid shock is exogenous (Wooldridge, 2002). Given the statistical insignificance of the test statistic (1.13 (0.289)), we fail to reject the null hypothesis of no endogeneity. Despite sufficient evidence that our instrument is strong, we do not have sufficient information in the sample to assume our interaction term may be endogenous. We proceed with discussions in the subsequent section, based on results from the OLS and LPM models. In the absence of endogeneity, IV estimators may have inflated asymptotic variance, thus relying on the estimates may lead to misleading statistical inference.(Geffersa & Tabe-Ojong, 2023; Wooldridge, 2010). Though the statistical insignificance of the Wald test of exogeneity attenuates concerns of endogeneity, we again refrain from making any causal inferences and emphasize that our estimates are associations due to the cross sectional nature of our data set.

Table 5: Instrument Relevance and diagnostics

	Codapec support (Dummy)
Instrument	
Community Share of farmers who received Codapec support	0.804 ***
	(0.111)
Controls	Yes
Validity tests	
F-statistics	53.957
R-squared	0.150
Wald test of exogeneity	1.13 (0.289)
Observations	990

Notes: Robust standard errors in parenthesis. Controls are same as the controls used in table 2 and 3. We estimate the Wald test of endogeneity from the control function IV probit regression where we instrument the interaction of dummy Codapec support and capsid shock with the interaction of community share of farmers who received Codapec support and capsid shock.

6.4.1 Effectiveness of Codapec support on yield and poverty

We evaluate the role of the Codapec support policy in mitigating the negative effects of capsid attack and ensuring farming success. In particular, we explore whether farmers who receive Codapec support amidst capsid attack are able to increase their yield and if such possibility translates into enhancing their poverty status. As emphasised above, despite the initial claims of possible endogeneity of our interaction term (capsid attack and capsid support dummy), we were not able to provide sufficient information to confirm this assertion. We discuss some interesting insights gained from the OLS and LPM models. First, using an OLS model with two specifications (without controls and with controls), we estimate the association between the interaction of capsid attack and Codapec support and yield, followed by an evaluation of the relationship between the interaction and income poverty using a linear probability model.

Regarding yield associations, we find a positive statistically significant relationship between our interaction term and yield (Fig 1). Our results show that farmers who receive Codapec support in the midst of capsid attack are associated with increases in their yield by about 24%. In other words, in situations buffeted by capsid related shocks, farmers who receive Codapec support tend to increase their yield as compared to their counterparts who do not receive the support. This implies that proper control of capsid attack significantly translates to yield gains. Importantly, this finding speaks to the associated yielding enhancing benefits of the Codapec program and aligns with findings from other programs such as the plant clinics which also increased the maize yield of farmers in rural Zimbabwe (Tambo et al., 2020).

Having explored the positive relationship between Codapec support and yield, we further verify the associations of the support on poverty. Fig 2, shows a negative relationship between our interaction term and income poverty. Farmers who receive Codapec support in the midst of capsid invasion are associated with a reduction in their probability of falling below the poverty line by about 16%. Situating it differently, cocoa farmers who received Codapec support amidst capsid invasion are 16 percentage points less likely to fall below the $1.90 poverty line than their counterparts who did not receive the support. This finding suggests that the Codapec support is pro-poor and could possibly provide a credible entry point in reducing poverty among rural farmers in Ghana. Overall, our results affirm the yield enhancing and poverty-reduction benefits of the Codapec policy support.

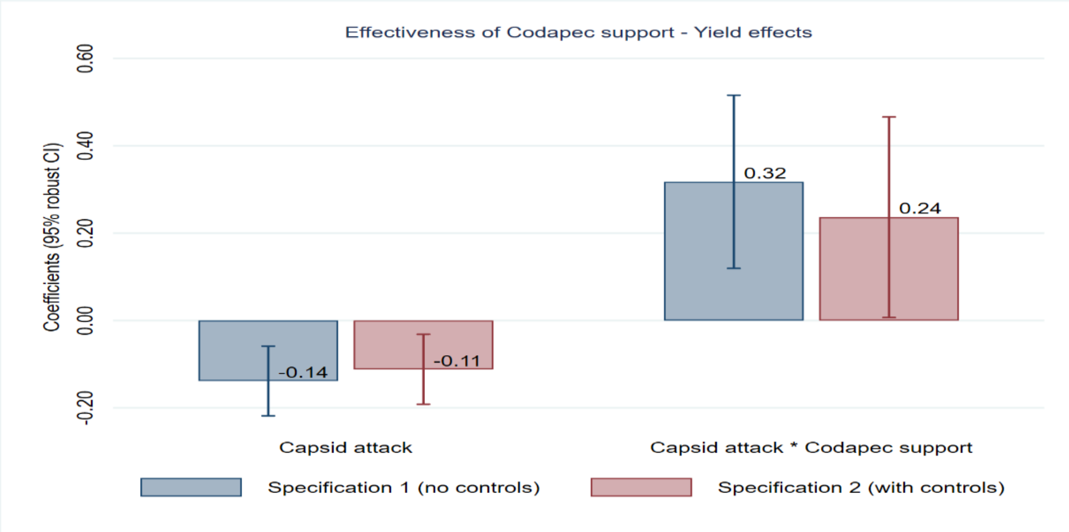

Figure 1: OLS estimates of Codapec support and yield (log)

Notes: Other controls include household size, age, gender and educational level of household head, land tenure, access to credit, distance to source of input, membership of producer group, size of cocoa farm, weeding frequency, distance to main plot of land for cocoa farming, cocoa intercropped, quantity of manure used, Codapec dummy, quantity of fertilizer used. We include community fixed effects in all specifications. Full numeric results in appendix *** p<0.01, ** p<0.05, * p< 0.1.

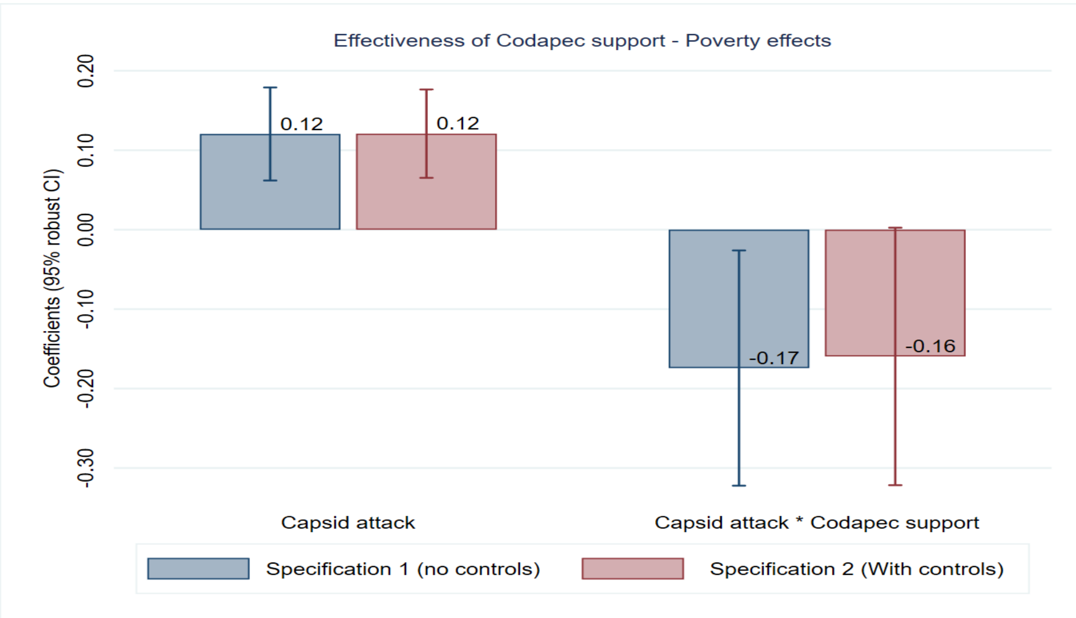

Figure 2: LPM estimates of Codapec support and income poverty

Notes: Other controls include household size, age, gender and educational level of household head, land tenure, access to credit, distance to source of input, membership of producer group, size of cocoa farm, weeding frequency, distance to main plot of land for cocoa farming, cocoa intercropped, quantity of manure used, Codapec dummy, quantity of fertilizer used. We include community fixed effects in all specifications. Full numeric results in appendix *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

7. Conclusion and policy recommendations

The threat posed by ecological shocks such as pests, especially in SSA remains a major concern for policy makers. In Ghana, the situation is not very different as capsid continues to be a great menace to cocoa production, affecting the welfare of cocoa farmers. In response to this threat, the government of Ghana, through the Ghana Cocoa Board (Cocobod), introduced the Codapec policy, a subsidy program geared towards supporting farmers in fighting pest attack. To provide evidence-based research to support and guide policymakers, we address three research objectives in our paper. First, we assess the associations of capsid attack on cocoa yield, and diverse income measures. Employing econometric methods, and exploiting the random spread of capsid attack, we find that exposure to capsid attack is associated with a reduction in cocoa yield, cocoa income, and per-capita income. This emphasizes and adds evidence to a growing body of literature on the yield and income reducing effects of ecological shocks.

Second, we investigate the relationship between capsid attack and poverty outcomes. We find that exposure to capsid attack is associated with an increase in cocoa farmers' probability of failing below the poverty line, widening of their poverty gap and poverty severity. Our results remain consistent over different model specifications (including inclusion of community fixed effects). Also, our Oster bound analysis shows that our findings are unlikely to be driven by omitted variables. Finally, we assess whether the Codapec policy mitigates or exacerbates yield and poverty effects of capsid attack. We document that in situations buffeted by capsid attack, cocoa farmers who receive Codapec support are likley to increase their yield and have lower probability of falling below the poverty line. Taken together, our results allude to literature emphasizing the income reducing effects of ecological shocks and offer additional insights on the poverty reducing effects of ecological shocks. In particular, we document that capsid attack may not only be associated with reducing the quality of life of cocoa farmers but can also push them below the poverty line and widen their gap in reaching the $1.90 poverty line. Also, our results on the effectiveness of the Codapec policy offer empirical support to studies assessing the effectiveness of control measures against pest attack. Although our results are tentative given the challenges in establishing causality, our findings are of enhanced benefits to policy makers in Ghana, given the importance of cocoa production to the economy.

Before proceeding to discuss the policy implication of our research, we issue some caveats that matter for the interpretation of our findings. First, despite arguing that the spread of capsid can be considered random, coupled with econometrically showing that receiving Codapec support amidst capsid attack may not be endogenous, we refrain from inferring causality. The cross-sectional data used in our studies makes it difficult to fully rule out all sources of endogeneity and assert causality. Future studies can use panel data and estimation techniques to improve the identification strategy in order to fully make any causal inferences. A second limitation relates to the measurement of our variables of interest. In our study, capsid attack was measured as a dummy variable, thus important information such as the intensity of the attack that can lead to heterogenous effects (Kassie et al., 2020),were ignored. It may be worthwhile for future studies to explore this gap to obtain comprehensive evidence on the heterogenous effects of these shocks. From a policy perspective, this will help in proper targeting of strongly affected households and more effective allocation of limited resources (Kassie et al., 2020). Lastly the estimates from regressions especially on the effectiveness of the Codapec policy are highly context specific. As discussed earlier, context matters when analyzing different agri-environmental policies and control measures, thus caution should be made in overly generalizing our results.

Our results offer clear and straightforward implications for policy and practice. Effective control of pests generally improves yield and welfare of farmers (Barzman et al., 2015; Tambo et al., 2020). More specifically, our findings show that the Codapec policy is associated with more benefits beyond increasing yield and could be a key policy in reducing poverty in rural Ghana. In this regard, our results point to the value of the Codapec policy in poverty reduction and rural development in Ghana. Ultimately, our result suggests that the Codapec policy, already in place in rural Ghana, should be well promoted by policy makers.

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