Article

Modelling Smallholder Welfare: Changing the Role of Interventions in Supporting Smallholder Cocoa Farmers and Forests in West Africa

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Abstract

Smallholder cocoa farmers in West Africa receive just 6 per cent of the final value of manufactured cocoa products and predominantly live in poverty. Current intervention strategies risk marginalising smallholder voices, inadvertently perpetuating hardship. Simultaneously, protecting West Africa's forests in the face of accelerating climate change is critical, creating a complex trade-off between smallholder welfare and forest conservation. This paper expands on the conventional focus of cocoa income as a sole measure of smallholder welfare, by incorporating broader metrics such as non-farm incomes, land size, food security, and access to environmental amenities. These factors are integrated within a novel agent-based simulation model. The model returns the focus to smallholder-level responses to interventions, offering new insights into the conditions under which smallholder welfare and forest preservation can be jointly improved.

Keywords: Farmer welfare, Environment, Smallholder, Agriculture, Agent-Based model

1. Introduction

Cocoa is an essential ingredient in a number of confectioneries, but it is also the livelihood of many in West Africa. In Côte d'Ivoire, the world's largest cocoa producing country, almost 1 million smallholder farmers, typically responsible for less than six acres of land, produce most of the country's cocoa (IDH 2018). This is likewise for 865,000 smallholder farmers in Ghana (Fairtrade Foundation 2025), the world's second largest producer. Together, these countries account for the majority of the world's cocoa output, yet cocoa smallholders in Côte d'Ivoire and Ghana vastly live in poverty. 82 per cent earn less than the living income benchmark (Waarts et al. 2021) and on average receive just 6 per cent of the final value of manufactured cocoa products.

To add to matters, cocoa smallholders have become inextricably linked to deforestation, where high price cash crops, like cocoa, are the largest contributors (Meyfroidt, 2018). Cocoa is responsible for 38 per cent of deforestation in Côte d'Ivoire alone (Kirioua and Brüntrup 2023). It is clear that there exists a trade-off with the local forest environment when addressing smallholders' welfare. New research must address the complex two-way relationship that smallholders have with their surrounding environment, and how this varies with regards to individual characteristics and endowments (Willock et al., 1999). This is the motivating factor behind this paper's research question - changing the role of interventions in supporting smallholder cocoa farmers and forests in West Africa.

In this paper, I develop an agent-based economic model, grounded in behavioural economics theory, which captures individual smallholder characteristics and behaviour, enabling a more nuanced simulation of how future interventions may impact profits, deforestation and welfare across a representative population.

My findings address the prior ineffectiveness of welfare interventions, and provide actionable insights for developing policies that simultaneously enhance farmer welfare and contribute to environmental protection goals. Profit-targeting interventions alone are constrained in improving smallholder welfare, and may even be counterproductive. I conclude the discussion by highlighting that prioritising interventions into non-income welfare correlates such as education and food security can improve overall welfare, without negative spillovers on the environment or neighbouring smallholders' welfare outcomes.

The paper is organised as follows. First, I review the existing literature which identifies difficulties devising policies and interventions that sustainably improve welfare outcomes in Ghana and Côte d'Ivoire. Sections 3 and 4 detail the construction of the economic modelling approach. In Section 5 this approach is applied to a simulated population of smallholders, each with unique attributes, to determine profit responses and the subsequent impacts on deforestation. The final welfare model, presented in Section 6, explains why interventions have so far proven ineffective. Section 7 discusses the model's robustness and its generalisability. Limitations and suggestions for future research are presented in Section 8. Finally, Section 9 draws together the paper in its concluding remarks.

2. Review of the Literature

2.1. Theoretical Framework on Smallholder Incomes and Welfare

Neoclassical Economics' utility theory dictates that when an individual's income increases, their consumption possibilities frontier shifts out, increasing the total possible quantities of goods that may be consumed, unambiguously increasing utility. However, it makes use of several assumptions; firstly monotonicity of preferences (a consumer always prefers more of a good to less), and secondly that rational individuals will maximise their utility (referred to as welfare henceforth) given the restrictions they face.

Applying such ideas to smallholder cocoa farmers is difficult. Previous research has shown that increasing smallholders' incomes from cocoa sales has weak transfer into improved welfare, or even into higher overall household income (Waarts et al. 2021), and negative externality effects on other components of welfare, such as food security (Anderman et al. 2014). And more broadly, lack of quality data is a contributor to the mixed opinions and responses amongst actors in the cocoa space on how to improve smallholders' outcomes (Laven, Bymolt and Tyszler, 2020).

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The existing literature offers multiple explanations for cocoa smallholders' poor overall remuneration, which establish the importance of characteristics and endowments in shaping their welfare. Firstly, smallholders are often subject to exploitation when selling their produce. Using household data from 520 farmholds in Ghana to investigate participation in maize price support programmes, Abokyi et al. (2020) discuss that even when selling under farmgate prices, smallholders lose out when traders buy low, and they possess too little bargaining power or price information to contest. Opatz (2020) concurs this, adding that cocoa farmers also have no way to differentiate their own product in order to charge higher prices. The outcome of this is an unsustainable sector, depicted visually in **Figure 1.**

In conjunction, poverty among smallholders in the cocoa producing countries is pervasive. Waarts et al. (2021) found that 82 per cent of cocoa farmers in Ghana and Côte d'Ivoire earn less than the living income benchmark, and extensive analysis of survey data in Northern Ghana found that none earnt a living income. Giller et al. (2021) validated this, finding that less than 25 per cent earnt more than 1.9 US$ per person per day absolute poverty line.

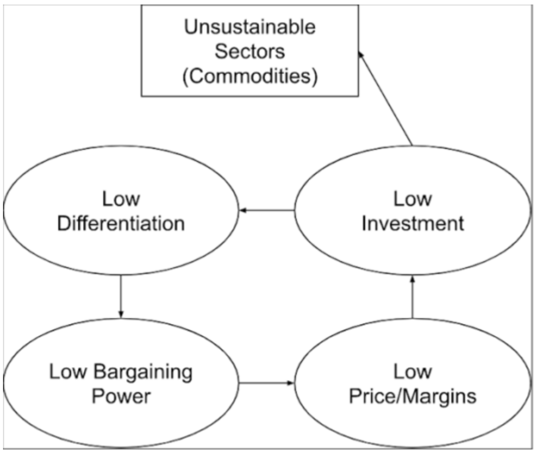

Figure 1: Adapted from Opatz (2020) and Simons (2015)

Several papers have explored the role of smallholders' individual characteristics on low incomes. Abokyi et al. (2020) use regressions methods on data from Ghana to find that older age and low levels of education could see farmers without the necessary market knowledge to negotiate fairer prices. Indeed, the average age of cocoa farmers is above 50 (Abukari, Zakaria and Azumah, 2022; Laven and Boomsma, 2012). Laven, Bymolt and Tyszler (2020) undertook household surveys in the cocoa producing regions to find that 95 per cent of self-determined household heads in Ghana's cocoa communities are male, and 90 per cent in Côte d'Ivoire. Abokyi et al. (2020) continued on to find that male smallholders were more likely to accept farmgate prices as they engage less with local markets, where higher prices could prevail. Age and gender therefore present as important factors in smallholder incomes in our research.

Poor incomes are exacerbated by the seasonality of cocoa and its sensitivity to weather and disease, which are responsible for shocks to output. Knudsen (2007)'s pioneering investigation into the incomes of households in Ghana's cocoa frontier originated this, finding that, though 98 per cent of native farmers earnt their primary income from cocoa, nearly all diversified into the non-farm sector to smooth their income and help to protect against shocks. Giller et al. (2021) build upon this and explain how, without stable on-farm incomes, farmers are not incentivised to reinvest into their farms. This may lead to stagnation in output and efficiency over time, also causing smallholders to turn to other sources of income in supplement.

It then becomes clear that our study must account for how smallholders allocate their time and resources across multiple forms of labour provision, as well as how they face their trade-off between farm income and the environment. It also proves integral to consider the individual characteristics of smallholders, such as gender and age, in this paper's simulation specification.

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2.2. Analysis of Previous Interventions and Implications for the Future

Governments, corporates and external organisations are tasked with drawing up welfare improvement policies that also combat deforestation in West Africa, pervading cocoa farming since the six-fold output increase in the mid 20th century (Ruf, Schroth and Doffangui, 2014).

A review of 24 studies on subsidies found the increase in income to be below 10 per cent regardless of subsidy size (Waarts et al., 2021). This disappointing outcome is coupled with the link to deforestation as a negative externality. Wentworth (2024) reported that from 2000 to 2010, agricultural subsidies in Côte d'Ivoire were 56 per cent higher than in Ghana, but this translated into a 3 per cent higher deforestation rate. Cash transfers were moderately more successful. Of nine studies on commodity farmers, two thirds found a significant positive impact on poverty measures, particularly by increasing food expenditure, but alone was not enough to impact aggregate poverty levels (Waarts et al. 2021).

It is perhaps intuitive that offering more land to smallholders would improve their welfare. Multiple studies substantiate this. Jayne, Chamberlin and Milu Muyanga (2012) studied spatial datasets from Africa to find that smallholders experience a large relative rise in income with even an incremental addition to land access. Though, in the cocoa producing regions, new land for cocoa production is likely to be cleared from forests.

An opposing stance is also present in the literature, suggesting that the relationship between land and measures of welfare beyond income, is not clear-cut. Studies have found negative relationships between cash crop output and food security. Anderman et al. (2014), use data from rural Ghana to regress the share of total land devoted to cash crops on the weight-to-age ratio of the household's children, finding a statistically significant negative correlation. Hashmiu, Agbenyega and Dawoe (2022) share the view that cocoa income alone is insufficient to guarantee food security in Ghanaian cocoa households. The significant negative relationships, though perhaps exacerbated by omitted variables such as other commodity prices, reinforce that income alone is not sufficient to proxy overall welfare.

Waarts et al. (2021), in their review of existing literature, found that interventions into commodity prices (targeting higher incomes for smallholders) translated between only 15 to 32 per cent into household income changes. Indeed, a grain price support initiative in Zambia had no effect on smallholders, benefiting only the largest 3.8 per cent of farms (>5 hectares), with rural poverty rates remaining the same (Jayne, Chamberlin and Milu Muyanga 2012).

Both Jayne, Chamberlin and Milu Muyanga (2012) and Danso-Abbeam and Baiyegunhi (2020) put forward that increasing the productivity of smallholder farms (agricultural intensification) could reduce the need for expanding lands, helping to reduce deforestation and risks from prioritising cash crops. And, higher technical efficiency improves household welfare, which in turn leads to further efficiency gains (Danso-Abbeam and Baiyegunhi, 2020). Despite the promise of these empirical findings, Waarts et al. (2019) maintain that this is not sufficient and that past interventions in Ghana and Côte d'Ivoire, specifically, did not improve average productivity per hectare.
Instead, recent research finds that approaches prioritising the personal attitudes and characteristics of smallholders are needed. Maguire-Rajpaul et al. (2021) are of this view, and explore a multiple environmentalities framework to highlight that recent sustainability initiatives in cocoa farming, especially corporate-led initiatives, reuse governance techniques that have marginalised the voices of smallholder farmers in the past.

Glover (1984) proposes outgrower schemes and contract farming as ways to improve smallholders' bargaining power and access to technology, with an overseeing firm for technical and marketing assistance. These methods preserve some autonomy of smallholders and also show promise in increasing efficiency and reducing uncertainty. Ruml, Ragasa and Qaim (2021) concluded via regression methods, using a treatment dummy variable for contract farming participation, that household incomes in Ghana were significantly higher for smallholders under resource-providing contracts than the baseline.

In determining farmers' decision to join a soybean contract farming group in Ghana, Selorm et al. (2023) found via probit analysis that participation is more likely in the most educated and experienced, and for larger household and farm sizes, those with credit access, and risk-averse individuals, as well as during periods of drought. However, the authors also found that

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contract farming participation decreased with household assets, suggesting popularity with farmers achieving lower incomes. This establishes the potential existence of an upper limit of income after which farmers would cease to participate in and benefit from contract farming.

A systematic review by Waarts et al. (2021) found that the effects of contract farming were positive on average, with a rate of return on household income of 1.32 across 8 studies. Though selection and survivor bias could contribute to overestimation, the authors affirm that the results are significant regardless, especially as smallholders are required to give up a portion of their autonomy in exchange for contract farming group membership. This can posit that contract farming improves welfare at least through the on-farm income channel.

So far, we have concluded that measures of smallholder welfare should include income from cocoa farming, income from other sources, household size, and farm size. And, that income from cocoa farming is a function itself of gender, age, subsidies and memberships of contract farming schemes. However, as Waarts et al. (2021) summarise succinctly, the impact of interventions in the past decades, if any, has not been sufficient to lift tree-crop commodity farmers out of extreme poverty at scale. This is particularly the case for interventions addressing a single welfare component, such as productivity or price increases (Waarts et al., 2021).

2.3. Existing Methodologies in Changing the Role of Interventions

Early research has employed a variety of modelling techniques that suit this paper's research objective. Bharwani et al. (2005) used price data collected from surveys of South African farmers to train a multi-agent simulation model which investigates household agents with varying adaptation options. This allowed the authors to explore the impact of situations which do not exist at present. In a similar vein, I take information from household-level surveys to inform the variables in this simulation model.

Discordance arises on the point of whether farmers, while utility-maximising, should be modelled as profit maximising. Money is often assumed in economic models to act as a measure of the extent to which individuals' utility is affected by changes in circumstances, as it is an easier measure than the abstract concept of utility (Edwards-Jones, 2006).

However, seminal work by Willock et al. (1999) and Gómez-Limón, Gutiérrez-Martín and Riesgo (2016) argues that this assumption fails to capture how farmers also make decisions based on a variety of socio-economic and psychological factors, making mathematical modelling more complex. Though the specifics of their papers are beyond the scope of this research, we can draw important conclusions from these methodologies for our model.

Recalling from the existing literature that modelling income as the dependent variable, to proxy welfare, is not sufficient to capture how farmers will be impacted by policy changes and interventions, we will employ on-farm income as one independent variable with a relevant weighting in farmers' welfare outcomes.

In our investigation we will also consider smallholders' unique characteristics. For example, Willock et al. (1999)'s model of Scottish farmers used survey data to determine associations between farmer attitudes and business-oriented or environmentally-oriented behaviour. The study found that farm size was positively correlated with environmentally-oriented behaviour, with a Pearson's correlation coefficient of 0.264. This provides practical insights that environmental interventions may not incentivise all farmers equally. It motivates the case for OLS regression analysis to establish correlations among the simulated sample of smallholder cocoa farmers to environmental variables.

3. Simulation Design

3.1. Agent Relationships

The following simulation encompasses the effects of agents who act on smallholder welfare exogenously; NGOs, the local government via policymaking, and corporations, through the medium of contract farming. Before we collect the results of the simulation, it is therefore pertinent to establish and validate these relationships, elucidating from which actors the simulated interventions arise. We also validate the inclusion of the environment as an 'actor' in smallholder cocoa farmers' welfare. Weather and random effects are also key players in actuality, the effects of which will be incorporated in Section 6.

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The role of policy and the government

The government has multiple methods of interacting with the central smallholder agents. It can attempt to influence smallholder welfare by adjusting the farmgate price of cocoa, or by providing subsidies on the production of cocoa, or by directly providing cash to smallholders as a means of improving the income aspect of welfare. These methods have shown varying success, as detailed in the literature review.

We will primarily focus on exploring the inefficiency of government-enacted subsidies in this paper, yet we will draw conclusions about preferable forms of government intervention in due course.

The role of NGOs, corporations and contract farming

NGOs are concerned more directly with farmer welfare, and with environmental protection, and can attempt to contribute to achieving this by providing environmental certifications to smallholders, and providing help with farming efficiency and education on sustainable methods.

Independent certifiers emerged in the 1990s, originally centred on certifying the 'good management' of forests to wood buyers purchasing from countries where public control systems were poor (Karsenty and Salau 2023).

Contract farming, however, refers to contractual agreements between smallholders and agribusiness firms serving to facilitate smallholders' connection to commercial markets, and the transfer of inputs and improved technology (Selorm et al., 2023).

In the interest of simplification, the effects of contract farming and otherwise improving farm efficiency and sustainability will therefore be coalesced into one form of intervention in this paper - targeting a higher 'A' constant, which we will later define as the farm efficiency level.

The forest as an environmental services provider

The rationale for inclusion of deforestation into the discussion and the subsequent model becomes evident when reviewing the high level facts surrounding deforestation and its links to cocoa agriculture. 90 per cent of global deforestation is related to agricultural activities, and accounts for 11 per cent of annual carbon dioxide emissions (Karsenty and Salau 2023). Zooming into West Africa, agriculture, forestry and land use was responsible for 38 per cent in 2012 and 43 per cent in 2019 of carbon dioxide emissions in Côte d'Ivoire and Ghana, respectively.

To substantiate this, and narrow the discussion to deforestation specifically, I employ data from the FAO (2024) and World Bank (2024) to validate the relationship between crop production and forest area in Ghana, in a multiple linear regression defined as follows:

$$\Delta \ln(ForestArea_t) = \beta_{1\Delta} Crop\mathrm{Pro}ductionIndex_t + \beta_{2\Delta} AnnualPopulationGrowth_t + \epsilon_t$$

	Dependent Variable[1]
	Log Forest Area
Crop Production Index	-0.0031388 (0.000)**
Annual Population Growth Rate	-0.1814968 (0.000)**
Constant	12.01889 (0.000)**
R^2	0.9284
Number of Observations	31

Table 1: OLS Regression Estimates

Data Sources: FAO (2024), World Bank (2024)

[1] $**p<0.05$

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A one-unit increase in the country's Crop Production Index is associated with a decline in forest area of 0.3 per cent, when controlling for population growth, isolating the effects of crop production from forest area cleared for living spaces. Both coefficients are highly statistically significant ($p = 0.000$) and calculated using robust standard errors. The regression output presents with a R^2 value of 92.84, confirming the suitability of the regression model in drawing this conclusion, though we should be mindful of the modest sample size.

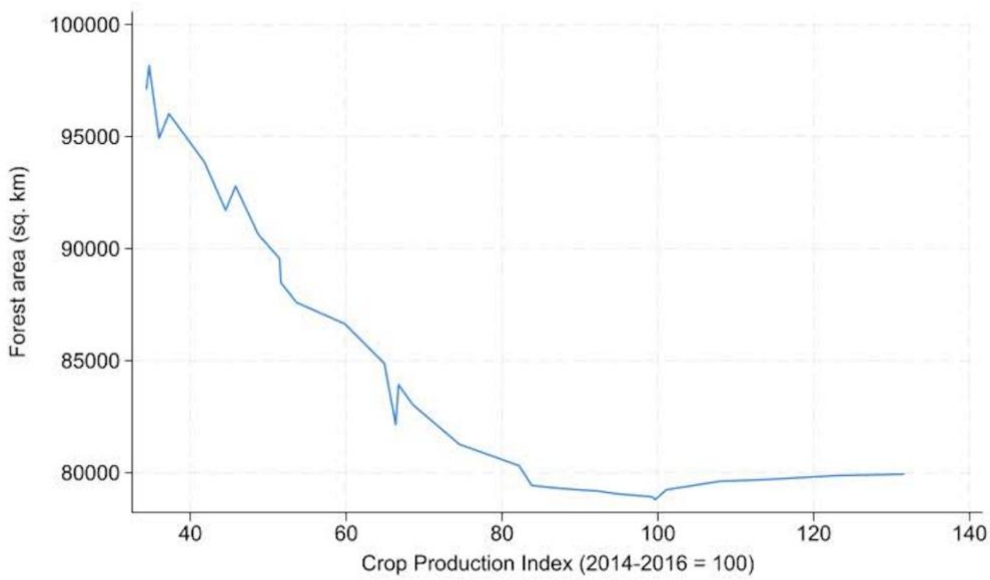

***Figure 2*:** Plot of Forest Area (Km/Sq) and Crop Production Index (2014-2016=100) Ordered on the x-axis.
Data Sources: FAO (2024), World Bank (2024)

And of forest area lost, cocoa contributes to a substantial proportion. Between 2001 and 2015, a third of Ghanaian forest area and one quarter of Côte d'Ivoire's was replaced by cocoa crops (Schneider et al. 2023). Using satellite imagery and deep learning, Kalischek et al. (2023) reached similar conclusions, that cocoa cultivation is a substantial driver of forest loss in protected areas of the two countries.

The environment surrounding cocoa farmers plays a myriad of roles in improving cocoa farming incomes and also farmer welfare. **Figure 3** depicts the primary channels through which this takes place, with the health of local soil, shade, pollination, and pest control facilitated by local wildlife some of the most tangible examples. Beyond this, the environment also serves recreational and aesthetic purposes for cocoa farming communities. As a result, we proceed considering the environment as a component of smallholder welfare.

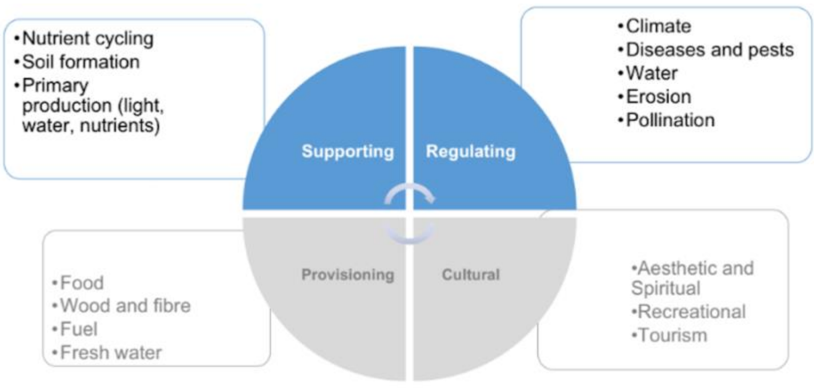

***Figure 3*:** Environmental Services by Category
Source: Mortimer, Saj and David (2017

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3.2. Agent-Based Modelling Framework

When investigating the interplay between environmental protection and farm profit, difficulty in accessing smallholder-level data complicates the inclusion of individual-level variables such as land endowment and personal characteristics. We require a robust method that facilitates this inclusion, given its importance in the literature.

To circumvent this issue, I develop an agent-based modelling framework that allows for a simulation of the smallholder population, accounting for individual characteristics and random variations over a number of variables. As Berry, Kiel and Elliott (2002) summarise, an agent-based model assumes that markets are created from the bottom up through the interactions of individual agents, proving its suitability to our research question. Though agent-based models make limiting assumptions and are not a replacement for real smallholder-level data, by taking into account individual decisions and preferences, they allow for a more nuanced approach to complex intervention design in regions where data is limited.

I employ and build upon the heterogeneous agent-based optimisation model by Andersen et al. (2015), calibrated to the unique endowments and characteristics of cocoa farmers in West Africa. Like Andersen et al. (2015), I assume that labour and land are the only two inputs into cocoa production and fix the relationship such that the amount of labour required for each additional hectare is given by:

$$\frac{dl^F}{dH} = (1+q)H \qquad (1)$$

Where $(1+q)$ is a marginal cost associated with an additional hectare of land and l_f^F is total farm labour in hours. This includes the smallholder themself, and any salaried labour working the smallholders' land. Andersen et al. (2015) do not state the detailed derivation of the optimal value of labour, l_f^F in their paper, but this can be found via Lagrangian Optimisation, constrained on the endowment of farmland H hectares, which I present in Appendix A. Taking A_f to be the farm efficiency parameter, as in Andersen et al. (2015) - defined as the ratio between the actual output and the potential output - w_f as the wage rate, and p_f the price of cocoa received by the farm. Then, the final result states that, for a given smallholder f:

$$l_f^{F*} = \frac{0.5(A_f p_f)^2}{w_f^2(1+q_f)} \qquad (2)$$

On-farm profit per day z_f can therefore be expressed simply as the following relationship:

$$z_f = (p_f)(A_f \cdot H_f) - (w_f \cdot l_f^F) \qquad (3)$$

We can subsequently use these results to establish the value of cocoa output, x_f kg, which is linear in H, and A.

$$x_f = A_f \cdot H_f \qquad (4)$$

H is achieved by integration on (1), and subbing this into (4) we obtain:

$$x_f = A_f \cdot \left(\frac{2l_f^{F*}}{1+q_f}\right)^{\frac{1}{2}} \qquad (5)$$

Or equivalently, now subbing in the definition (2):

$$x = A_f \cdot \left(\frac{2*\left(\frac{0.5(A_f p_f)^2}{w_f^2(1+q_f)}\right)}{1+q_f}\right)^{\frac{1}{2}} \qquad (6)$$

Finally subbing (2) and (6) into (3) the profit function which will be employed as the daily profit of the smallhold is as follows:

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$$z_f = \left(p_f \cdot A_f \cdot \left(\frac{2 \cdot \left(\frac{0.5(A_f \cdot p_f)^2}{w_f^2(1+q_f)} \right)}{1+q_f} \right)^{\frac{1}{2}} \right) - \left(w_f \cdot \left(\frac{0.5(A_f \cdot p_f)^2}{w_f^2(1+q_f)} \right) \right) \tag{7}$$

3.3. Variable Specification

The findings discussed allow me to fit the model variables to real-world data consistent with the case of smallholder cocoa farmers in West Africa, in order to facilitate a credible simulation.

Prices and Costs

The price of cocoa received by smallholders is often determined exogenously, given by the prevailing farmgate price in the region. To account for this, the model uses an average price, p US$/kg, of $1.73 informed by field surveys by Laven, Bymolt and Tyszler (2020).

I also define that the marginal cost of labour, given by $(1 + q)$, is calculated using a q drawn randomly from between {0.2, 0.4}. This window is chosen as a reasonable assumption that working the new land added to one's endowment will have differential labour required than just working one's existing endowment, for example if travel to the new land incurs costs (Andersen et al., 2015), though these are likely to be rather small.

Wages

The wage paid to cocoa farmers, w, will incorporate the 'wage' that the smallholder pays to themselves, and be equal to the rate paid to any hired labour working the smallhold. This average daily salary is informed by the International Cocoa Initiative (2017), which establishes, at the lower end, a wage of $0.40 per day. Using this number as a reference, I create a window from which wage values will be randomly drawn, in order to capture individual variation.

Given that I also assume cocoa farmers work for 8 salaried hours per labour day, supported by van Schoonhoven (2021)'s depiction of the working life of West African cocoa farmers, these definitions allow the basic hourly wage for the smallholder and each worker employed on the smallhold to be:

$$\left\{ \frac{\$0.36}{8} \le w \le \frac{\$0.44}{8} \right\}$$

Efficiency

Average efficiency in most cocoa producing regions is low. Recalling that the efficiency parameter A measures the ratio between the actual output and the potential output, Ashanti Region Ghanaian cocoa farmers are 48 per cent efficient (Besseah and Kim, 2014). This measure often falls within a consistent range within the literature, with Danso-Abbeam and Baiyegunhi (2020) finding mean overall technical efficiency of Ghanaian cocoa farmers at 44 per cent. I proceed with a rounded 0.5 as the starting value for the farm efficiency level, A.

Cocoa season days

Estimates of how many days of on-farm labour exist for the smallholder can be informed by the length of the cocoa season. The West African cocoa season consists of a main crop season and a light crop season. These coincide with the two rainy periods, from April to July, and September to October of a given year (Asitoakor et al., 2022). Though, the exact length of these seasons can vary.

Tawiah (2024) places the main cocoa season during the 6 months from October to March, and the lighter season from April to September. In the interest of standardising the number of days worked across smallholders to ensure comparability of their profit functions, this paper will use 250 labour days, allowing total profit per season, Z_f to be calculated.

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3.4. Inclusion of smallholders' specific attributes

Age

Age can be incorporated into the profit function for farmers, via the coefficient A, capturing how efficiency is likely to be decreasing with age. We have already established the average age of farmers to be above 50, and 28 per cent sit within the 46-55 age bracket, determined by Laven, Bymolt and Tyszler (2020). We proceed to remove 0.02 from the value of A for those 56-65, at a rate of 20 per cent of the smallholder population, and a further 0.02 for those 66 and older, at 14 per cent of the population. This way, the lowest value of A does not fall below the lowest value established in the empirical investigations detailed in the previous section of this paper.

Gender

95 per cent of self-determined household heads in Ghana's cocoa communities are male (Laven, Bymolt and Tyszler 2020), leaving 5 per cent assumed female. Recalling that male smallholders were more likely to accept lower cocoa prices (Abokyi et al. 2020), this allows us to assume that the distribution of prices received for the sale of cocoa is weighted at 95 per cent receiving the lower price of 1.73 US$/kg, and 5 per cent, a higher price of 1.8 US$/kg. This allows some variation in price received in each smallhold on account of gender, improving the representativeness of the model.

4. The Deforestation Decision

This paper encompasses the decision of smallholders to expand their own land in aim of improving welfare at the expense of the surrounding forest. Together with the profit equation, the results inform the construction of smallholders' welfare in the complete model, where I will consider individual responses to income changes and interventions.

In order to calibrate the results towards the experience of smallholder cocoa farmers, I first must make some assumptions in constructing the deforestation decision. Given the prevalence of poverty among cocoa smallholders, with many lacking the capacity to invest or access credit with which to invest (Waarts et al. 2021), it is a reasonable assumption that very little of existing farm profit is reinvested in the next period. Despite a dearth of literature on specific reinvestment rates for cocoa farmers, very little overall African investment reaches the Agriculture sector, with only 4.69 per cent of capital allocated there (Lim et al., 2024). Using this as a guide, a value of 5 per cent of farm profits is assumed available for reinvestment. It is also taken that, alongside the expected labour costs to maintain one further hectare of land each season, there is a fixed upfront cost of 400 US$, which encompasses the additional equipment and temporary labour that will be required to clear and prepare forest land for cocoa cultivation. This number is informed by the rounded estimate of total land-related cocoa production costs in US$/kg/ha (Yahaya et al. 2015).

Then, deforestation in hectares per smallhold per season is determined as:

$$D^*_{f,t} = \frac{(0.05 * A_f * Z_{f,t-1})}{\frac{(w_f \quad * L_f)}{H_f(1+2q_f)} + (400)} \tag{8}$$

Where (8) is a function of reinvested profit from the previous season, $t-1$, the efficiency with which it is reinvested, and the expected cost of labour per additional hectare for each smallhold. The expression thus captures the monetary capacity with which each smallhold has to deforest surrounding land divided by the costs per hectare of the new land. Though conceptually similar to Andersen et al. (2015)'s specification of deforestation, we add the additional fixed costs, and consider for simplicity that the marginal cost assigned to additional hectarage of deforested land and endowed land are equal, therefore depicted in (8) as their summation $2q$.

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5. Simulation Results

5.1. Base Case Simulation

I first explore the base case simulation, omitting any interventions, to provide a reference of smallholder cocoa profit and deforestation values, and to check consistency with the real data.

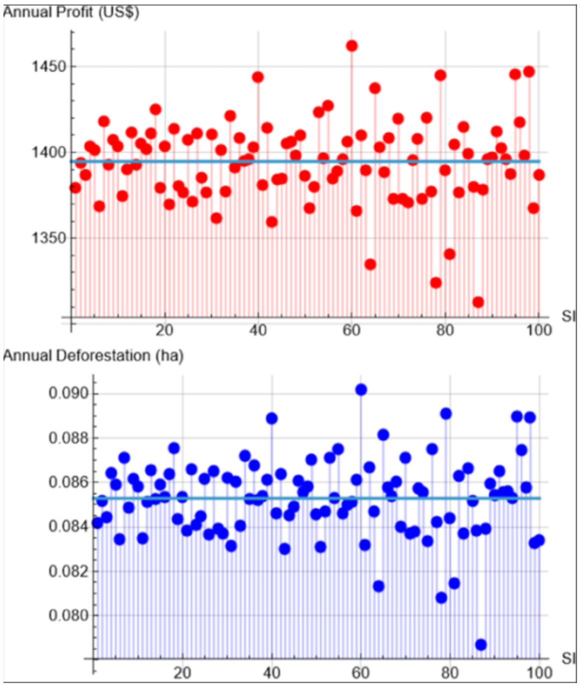

Figure 4: Average of 30 Trials of the Population Simulation

5.2. Applying a Subsidy

Next in **Figure 5**, the model returns the case where the equivalent of a 10 per cent price subsidy is added to all cocoa units produced by a smallholder, such that in place of p, the model computes profit and deforestation using $(1.1 * p)$.

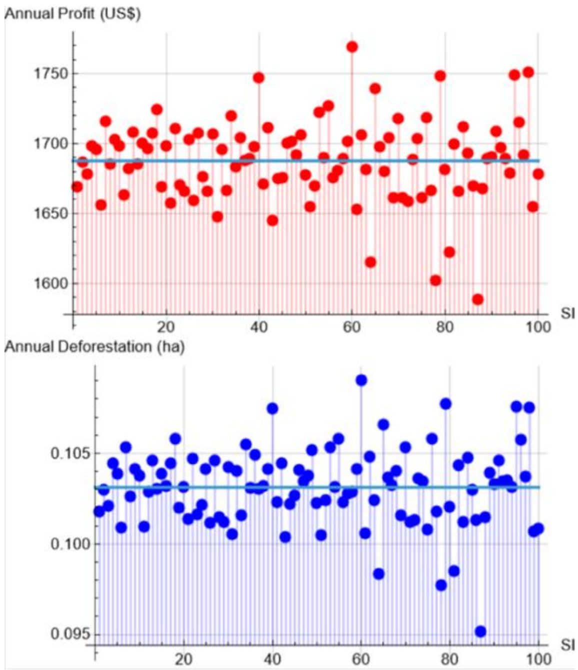

Figure 5*:* Average of 30 Trials of Population Simulation with Price Subsidy

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5.3. Adding Contract Farming

I then compute the effect of contract farming, which could successfully improve the efficiency of production of each smallholder, represented by an increase in A. For this simulation, where A was previously applied, the model applies $(1.6 * A)$, such that the most productive members of the population reach a maximum efficiency level of 80 per cent.

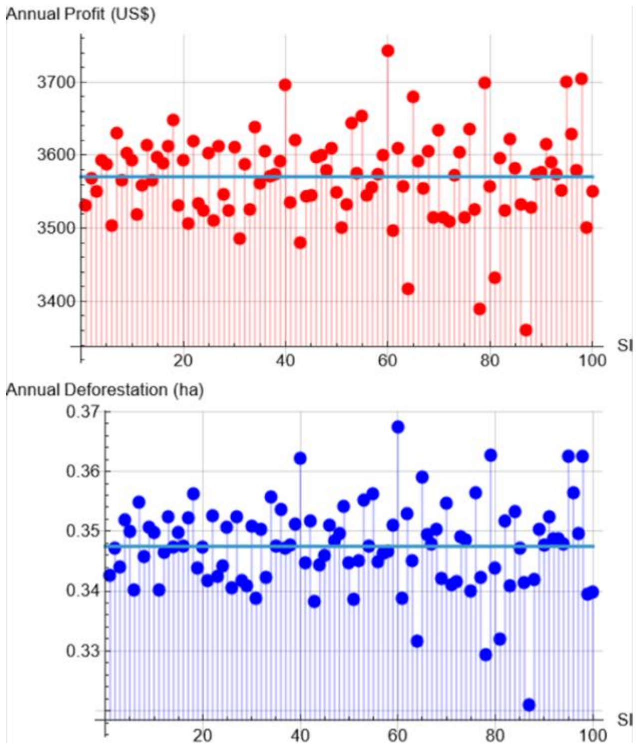

Figure 6**:** Average of 30 Trials of the Population Simulation with Contract Farming

The model output allows several key inferences to be drawn. Firstly, the overlay between profit and deforestation observed in **Figure 4** allows for a clear observation of the interconnectedness of the two variables and their movement in tandem. The proportion with which deforestation increases with profit can be calculated, on average, to be 0.000060945 ha/US$.

This appears minute, but when applied across the estimated 865,000 smallholders in Ghana, this is approximately 1.33 per cent of total forest area lost per season because of cocoa smallholder farming - calculated using the 2005 forest area statistics from Butler (2013) - in only the base case. This estimate nears that provided in the source data for Ghana's annual deforestation rate, at 1.89 per cent.

When considering the effects of a 10 per cent price subsidy awarded to the output of cocoa, the average level of profit, expectedly increases, to 1687.6 US$ per smallhold per season, visualised in **Figure 5**. This is an increase of 21 per cent on average, in a greater proportion than the subsidy itself, contesting some of the literature we have put forward in this paper's review that subsidies prove ineffective on incomes. This is likely due to the setup of the profit function employed in this paper, where the price variable, p, appears twice, as price itself, and as a component of the output function, as below:

$$z_f = \left((1.1p_f) \cdot A_f \cdot \left(\frac{2 \cdot \left(\frac{0.5(A_f(1.1p_f))^2}{w_f^2(1+q_f)} \right)}{1+q_f} \right)^{\frac{1}{2}} \right) - \left(w_f \cdot \left(\frac{0.5(A_f(1.1p_f))^2}{w_f^2(1+q_f)} \right) \right) \qquad (9)$$

It's perhaps more noteworthy that a large variation exists in the increase of deforestation in response to the 10 per cent price subsidy, by the value of profit in the previous period. Farms with low profits in the previous period presented much lower increases in deforestation levels, around 11 per cent, versus large-profit farms, which experienced an upwards of 20 per cent increase in hectares deforested following the subsidy.

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Increasing farm efficiency by a factor of 1.6, allowing the maximum efficiency to reach 80 per cent, increases profit by 156 per cent on average, but with a considerable negative spillover on deforestation. The average hectares deforested per smallhold per season reaches 0.347. This is a 308 per cent increase to the base case, depicted in **Figure 6**. The scale of increase remains consistent irrespective of the original value of farm profit.

5.4. Checking consistency with the literature

I validate for robustness that the model's initial predictions are realistic, and consistent with the literature, before drawing inferences from its findings.

Profit values predicted by this paper's model match exceedingly well to Laven, Bymolt and Tyszler (2020)'s field study. The mean profit value predicted is 1,395.30 US$/season. Laven, Bymolt and Tyszler (2020) record 1,522 US$/season as the mean cocoa income in Ghana, where they note that the average among 'typical' farms (excluding large farms) was 1,225 US$/season.

In per hectare terms, these also match the calculations of Yahaya et al. (2015), which found an average of 177.5 US$/ha net profit across all farm sizes in the study area of East Ghana. This paper's model projects an average of 172 US$/ha.

The sensible match to Laven, Bymolt and Tyszler (2020)'s field survey data and Yahaya et al. (2015)'s study provides confidence that the model is a useful tool in projecting and analysing changes to smallholder profits.

6. Welfare Investigation

6.1. Defining Welfare

Seminal papers widely discuss that estimating the welfare of heterogeneous agents is a complex and multidimensional exercise (Carpantier and Sapata, 2015). This paper aligns with concepts of 'objective welfare' which must reflect both an individual's material living conditions and the quality of their lives, as in Voukelatou et al. (2020). The authors propose several observable contributors to this definition of welfare such as health, jobs, and the environment.

Much like Glewwe (1991) in their investigation into household welfare in Côte d'Ivoire, the welfare expression includes functions of multiple welfare correlates. Among those suggested are earnings functions, agricultural production functions, variables influenced by government action, variables capturing human capital such as education, physical assets, and community characteristics, which in this paper will focus on local amenities in the form of environmental services from surrounding forest areas.

First, a multiple linear regression model is used to establish relationships between welfare, farm income, and the correlates of welfare; income from other sources, education, land and household size, food security and the local environment. As discussed, welfare of rural smallholders, and as in most welfare investigations, is subject to an element of randomness, particularly due to weather and seasonality of crops, in the case of cocoa farmers (Knudsen, 2007). This motivates the retention of a random error term, v_f, in both the expression for welfare and the visualised model.

To maintain consistency with the profit and deforestation model in the welfare estimation, we will employ the dataset of Laven, Bymolt and Tyszler (2018)'s household survey data, collected from 3045 households in cocoa-growing regions in Côte d'Ivoire and Ghana. Due to an unavailability of an observed variable capturing welfare itself, we must employ a proxy variable in the place of the dependent variable, household welfare, that is relevant to the case. Appendix B details the summary statistics of each variable.

First, in column (1) I run a standard log-log OLS regression, recording the coefficient estimates and p-values. Then, in column (2) fixed effect regression estimates are generated by clustering the data across the 14 regions studied. Finally, mean centered OLS estimates are presented in column (3). Recentering the variables about their means makes intuitive sense in the context of this empirical investigation, as it allows for a clearer interpretation of the constant term as the baseline welfare value when the other household attributes are at their average level, and can help to address concerns of multicollinearity by reducing potential correlation between the predictor variables.

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	Dependent Variable[2] - Log Welfare*		
	(1) **OLS regression estimates**	**(2)** **Fixed effects (cluster by region) estimates**	**(3)** **Mean centered regression estimates**
Log Profit from Cocoa	0.2190771 (0.000)**	0.2388951 (0.012)**	0.2190771 (0.000)**
Log Land Owned	0.1960237 (0.000)**	0.2349585 (0.000)**	0.1960237 (0.000)**
Log Food Security	0.4219361 (0.001)**	0.3386255 (0.035)**	0.4219361 (0.001)**
Log Environmental Services	0.2960953 (0.000)**	*(Omitted)*	0.2960953 (0.000)**
Log Other Income Sources	0.4289579 (0.000)**	0.42499 (0.017)**	0.4289579 (0.000)**
Log Education	0.4598402 (0.015)**	0.4093477 (0.002)**	0.4598402 (0.000)**
Log Number of Household Members	-1.088603 (0.000)**	-1.095189 (0.000)**	-1.088603 (0.000)**
Constant	-2.37748 (0.000)**	-3.886243 (0.000)**	-3.228025 (0.000)**
R^2	0.5455	0.3077	0.5455
Number of Observations	921	921	921

**Log Welfare is defined as the negation of log likelihood of living below the 2.50 US$/day line.*

Table 2: Regression Estimates

[2] **$p<0.05$

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I select the dependent variable to be likelihood of living below the 2.50 US$/day line for the welfare proxy, as this variable captures a holistic measure of the welfare of smallholders over continuous expenditure variables, particularly when

expenditure data is sparse or unavailable as is often the case in rural cocoa farming regions. Since poverty lines are used as a widely accepted measure of welfare by global NGOs such as the World Bank (Hasell, 2022), it is also fit for purpose in policy and intervention related works. The 2.50 US$ line, as opposed to the lower 1.25 US$ line, allows for a poverty measure more in accordance with recent changes to global prices and PPP across nations (Hasell, 2022). Employing the use of the log-log level here allows for ease of interpretation of the following results.

Inclusions were made of control variables, age and gender, given their importance in the set up of the profit model. However, they were omitted from the final table due to insignificant p-values, likely resulting from collinearity with profit and income variables. A variable capturing the number of members in a given household was retained due to its statistical significance, and intuitive importance when considering welfare changes resulting from changes to income in poorer households.

Profit from Cocoa, Land Owned, Food Security, Other Income Sources and Education are each significantly positively correlated with Welfare in all regression specifications, perhaps to be expected given the strength of arguments presented in the literature surrounding each of these variables. Using the mean-centered OLS regression estimates from regression (3) as our reference, a 1 per cent increase in Profit from Cocoa is associated with a 0.22 per cent increase in smallholder welfare. Education presents the largest increase in Welfare per 1 per cent increase in its level, at 0.46 per cent. This argues the case for targeting education of smallholders as a means to improve welfare, not only via on-farm profit but also as a contributor to welfare itself.

Environmental Services is the negation of pesticide costs, which captures the benefit of natural pesticides, as one form of services a smallholder receives from the surrounding forest area. This is significantly positively correlated with the welfare proxy in both regressions where it is present. This allows for the inference that environmental services are an important correlate to smallholder welfare, highlighting the importance of tackling deforestation for the joint benefit of the environment and smallholders.

As is conventional when modelling individual welfare, I employ a Cobb-Douglas welfare function for this modelling exercise, due to its simplicity and ability for each different dimension to take a different weight (Villar, 2023), This allows one to normalise each of the variables' estimates in (3) into the respective elasticities for the welfare function, such that their summation is 1, ensuring constant returns to scale. The Cobb-Douglas function of welfare is therefore constructed in the multiplicative format below, holding for any smallholder f at any time $t \geq 1$:

$$Welfare_{f,t} = Z_{f,t-1}^{0.23} \cdot (Land\ Owned)_{f,t}^{0.20} \cdot (Food\ Security)_{f,t}^{0.45} \cdot (Environmental\ Services)_{f,t}^{0.32} \cdot (Other\ Income)_{f,t}^{0.45} \cdot (Education)_{f,t}^{0.50} \cdot (Number\ of\ Household\ Members)_{f,t}^{-1.15} \cdot e^{v_{f_t}} \quad (10)$$

Or, as expressed in the equivalent additive format, which this paper will use for modelling purposes:

$$ln(Welfare_{f,t}) = 0.23ln(Z_{f,t-1}) + 0.2ln(Land\ Owned_{f,t}) + 0.45ln(Food\ Security_{f,t}) + 0.32ln(Environmental\ Services_{f,t}) + 0.45ln(Other\ Income_{f,t}) + 0.5ln(Education_{\ f,t}) - 1.15ln(Number\ of\ Household\ Members_{f,t}) + v_{f,t} \quad (11)$$

It is required due to the log-log specification that the below holds:

$$\{Z_{f,t-1}, Land\ Owned_{f,t}, Food\ Security_{f,t}, Environmental\ Services_{f,t}, Other\ Income_{f,t}, Education_{\ f,t}, Number\ of\ Household\ Members_{f,t} > 0\}$$

While, in actuality, positive income from other sources may always hold, this assumption is plausible to make for this exercise. Knudsen (2007)'s review of Ghanaian cocoa frontier households found that the average number of income earning activities was 2.17.

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Environmental Services is a variable decreasing proportional to the increase of deforestation with respect to profit, found via the simulation in Section 5 to be at a rate of 0.000060945. The same mechanism increases Land Size by the same proportion, requiring:

$$\begin{aligned} Environmental\ Services_{f,t} &= Environmental\ Services_{f,t-1} - 0.000060945 \cdot Z_{f,t-1} \\ Land\ Owned_{f,t} &= Land\ Owned_{f,t-1} + 0.000060945 \cdot Z_{f,t-1} \end{aligned} \quad (12)$$

It is then possible to simulate the welfare of a single smallholder at a fixed point in time, and plot how welfare interacts with profit, Z_f. To account for the necessity of random variance, the error term ν_f for the household is randomly drawn from a Normal Distribution $N \sim (0{,}0.9198767)$, with standard deviation determined by the residuals generated alongside **Table 2.**

6.2. Simulating Welfare

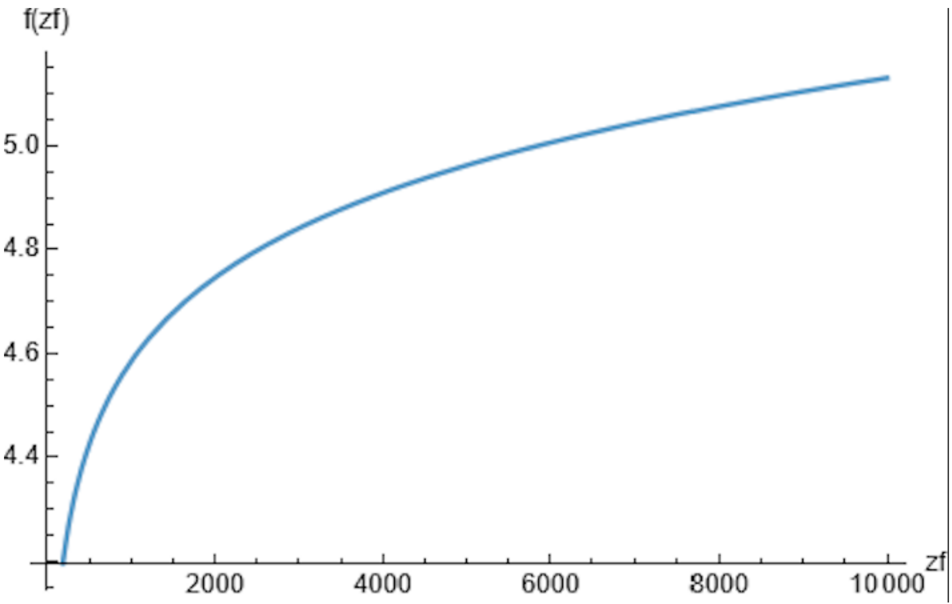

***Figure** 7*: Plot of individual welfare, f(zf), by profit, zf

From **Figure 7**, we observe that welfare increases with profit, within a reasonable range of profit values $\{0 \leq Z_f \leq 10{,}000\}$. Due to the log-log specification of the welfare function, the concavity of welfare decreases as profit rises, depicting a diminishing rate of welfare increase. This is again a reasonable result. The concept of diminishing marginal utility is ubiquitous in modern economic theory, and many welfare investigations make use of additively separable concave utility components like income (Kimball et al., 2015). Such is the case in this paper and thus, I would not expect welfare to be linearly increasing in profit.

However, considering a smallholder in isolation in the context of deforestation is unlikely to capture the full interplay between the loss of environmental services resulting from deforestation, and welfare. Now considering the cumulative effect of 100 surrounding smallholders, which will detract from the available forest area and the available environmental services, the variable is newly defined as follows:

$$Environmental\ Services_{f,t} = Environmental\ Services_{f,t-1} - (100) \cdot 0.000060945 \cdot Z_{f,t-1} \quad (13)$$

The specification of $Land\ Owned_{f,t}$ remains the same for the individual smallhold, as they can add to their own farmland at the same rate as in the base case.

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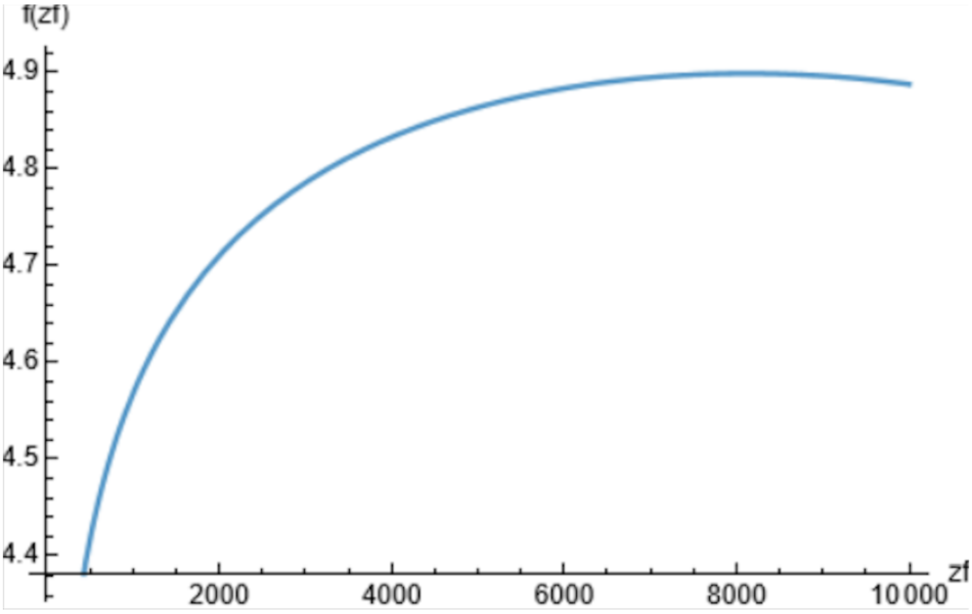

***Figure 8*: Plot of individual welfare, f(zf), by profit, zf, with 100 surrounding smallholders**

The model of welfare for the individual smallholder begins to collapse much sooner when the cumulative effect of neighbouring smallholders is introduced, with the global maximum of profit appearing at 8,124.89 US$, depicted graphically in **Figure 8.**

Extending this idea to consider the impact of 375 neighbouring smallholders, the model collapses entirely within a window of $\{0 \leq Z_f \leq 5{,}000\}$. The global maximum value of profit can be computed to be 2,108.63 US$. Welfare as a function of profit, $f(Z_f)$, decreases beyond this point, as in **Figure 9**. This is a significant result, as many interventions presented in this paper target profit levels beyond this maximum, recalling the simulated case of contract farming in **Figure 6.**

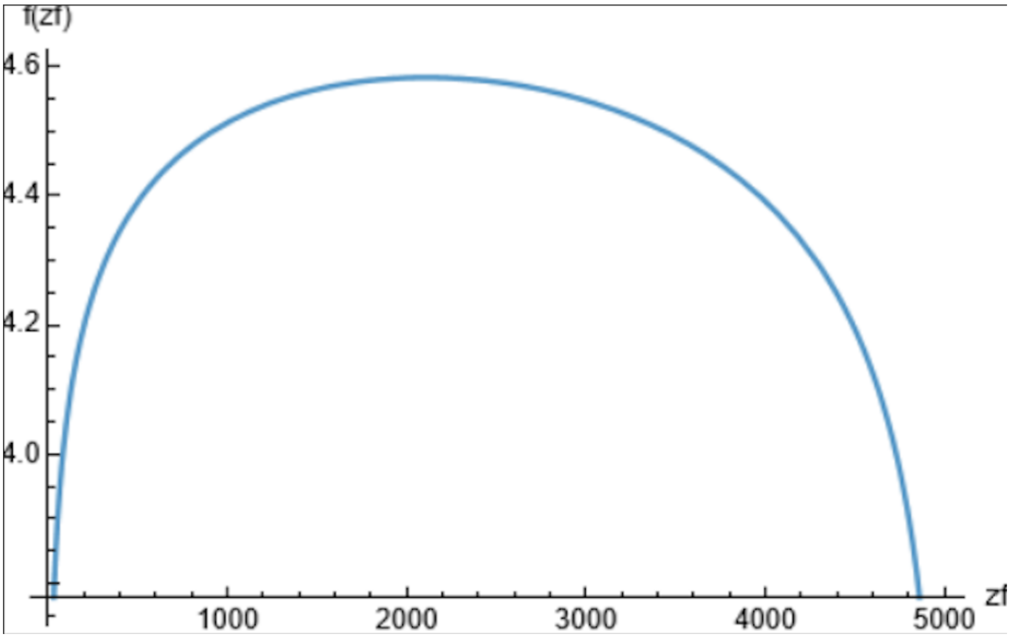

***Figure 9*: Plot of individual welfare, f(zf), by profit, zf, with 375 surrounding smallholders**

A general expression for the global maximum profit in this system, for any valid choice of parameters $Environmental\ Services$, $Land\ Owned$ and $n \geq 1$ smallholders, can therefore be found analytically to be of the form:

$$\frac{0.22}{Z_{f,t-1}} + \frac{0.2\cdot(n)\cdot(0.000060945)}{Land\ Owned_{f,t-1} + (n)\cdot(0.000060945)\cdot(Z_{f,t-1})} - \frac{0.32\cdot(n)\cdot(0.000060945)}{Environmental\ Services_{f,t-1} - (n)\cdot(0.000060945)\cdot(Z_{f,t-1})} = 0 \quad (14)$$

It becomes clear from the existence of this global maximum that interventions targeting higher farm profits have only limited scope to improve welfare, when considering a smallholder's place within a larger community of cocoa farmers. Beyond this, profit interventions may not only be ineffective at sustainably improving welfare but may detract from it. An upwards shift in the welfare function (11), without disamenities, is therefore only possible from increasing non-profit welfare correlates, such as education, food security, or other sources of income.

7. Robustness and Generalisability

As a test of robustness, it is essential to explore the generalisability of the results put forward in this paper, to ascertain under what assumptions that the model remains robust. The assumptions of fixed costs and reinvestment rates have varying flexibility. Statistically robust results are generated only when the fixed cost of deforestation remains above 350 US$/ha. This may be relaxable, in a case where it is not assumed that all smallholders in the population exercise deforestation. However, it highlights a constraint to the model in its current form. Already highly technically efficient smallholder communities may be subject to much smaller fixed costs of land clearing, for which this constraint may not be suitable.

The assumption of a 5 per cent reinvestment rate is also a key component in the determination of deforestation caused by smallholders. For robust results, the reinvestment rate must remain below 7 per cent in the current specification of this model. Assuming small reinvestment rates is acceptable for tree-crop commodity farmers (Waarts et al., 2021). Though empirical works focused on other commodity types, such as Agbonlahor et al. (2015)'s study of Sub-Saharan African vegetable farmers found reinvestment rates of 13.9 per cent, pointing to the restriction of the model to tree-crop or comparable commodities only.

The model remains entirely robust, however, in some parameters for which I have made assumptions. The model outputs statistically viable results for a value of q within the marginal cost, $(1 + q)$, anywhere within the range $\{0 \leq q \leq 1\}$. This allows flexibility to adapt the model to regions where the marginal cost of additional labour may vary greatly. This can be confirmed by establishing that the output of 30 simulations drawing q randomly from this window results in a deforestation rate of 1.69 per cent, which is a reasonable estimate against the real-world value, and an average smallholder farm profit of 1258.9 US$/season, consistent with the small farm average of 1,225 US$/season in Ghana (Laven, Bymolt and Tyszler, 2020). The welfare regression conducted initially presented with a statistically significant Breusch-Pagan/Cook-Weisberg test for heteroskedasticity, suggesting that the variance of the error terms is not constant across the regression observations (see Appendix C). This is believable in household-level income data, as for example, low income households have a lower propensity to spend income, thus leading to low variation within this group, as opposed to higher income households which have higher discretionary spending (Williams, 2020). To address these concerns, the final regressions presented in **Table 2** were calculated using heteroskedasticity robust standard errors to ensure the utility of the findings.

Beyond the specifics of the parameters, this paper's model has practical generalisability, and produces insightful results. It indicates that a mechanism in which profit improvements increase deforestation and subsequently diminish welfare can and does exist, elucidating why previous welfare interventions may have fallen short. It is then possible that this mechanism also exists in other contexts.

8. Limitations and Scope for Future Work

When considering the relevant community effects of deforestation, the individual welfare function presented in **Figure 7** is no longer reflective of the reality. If it is likely that real world smallholders do not have complete information about others in their community, disillusionment could arise when more profit is overall not better, due to these unobserved community effects.

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This disillusionment can be a generator of conflict and strife. Ohlsson (2000) effectively explores the existence of such livelihood conflicts in agricultural regions. This again highlights the importance of education and institutions as tools to mitigate these risks and to manage the environment collectively. Definitively what such institutions may look like lies beyond the scope of this paper, but collective agencies of cocoa smallholders managing environmental resources could be one avenue to protect their joint interests, as raised by Maguire-Rajpaul et al. (2021).

Of course, this paper's model could be extended to account for other topics in environmental economics, such as climate change by incorporating temperatures into the production function for cocoa. These effects would also be amplified in scenarios where smallholders have a high discount rate for the future. For myopic smallholders, even with improved education, they may place less emphasis on the long-term health of the environment than their own immediate welfare, leading to profit taking precedence over forest preservation, despite the negative feedback I have shown it may have in subsequent periods.

It is likely that the model also excludes real-world constraints on the value of the deforestation undertaken, such as a physical lack of availability of forest, or as Willock et al. (1999) propose, differing individual attitudes towards the environment. In reality some similarities could arise to other notable models, such as the Environmental Kuznets Curve where environmental disamenities increase with GDP initially, but beyond a certain level, begin to decline. Perhaps beyond a certain value of profit, smallholders are incentivised to operate more sustainably as they now have the spare means with which to do so.
Adjustments to the deforestation specification in (9) could ensure that when deforestation is unavailable, reinvestment of profits may be undertaken as replanting on a smallholder's own land, subject to costs, in line with Ruf and Burger (2018). Likewise, within the model assumptions, there is no option that farmers spend non-farm income on farm expansion. If this is the case, the deforestation result could be larger. However, empirical works suggest that the reinvestment of non-farm incomes is unclear in African farming households and is highly dependent on credit availability and the nature of alternative income flows (Reardon et al., 1994).

Future works could also expand the definition of A, which is a broad efficiency parameter in this model, to investigate the various channels through which smallholder efficiency can be improved, drawing conclusions for targeted efficiency interventions.

From a computational perspective, though the model can be adjusted to compute any number of trials of any sample size of smallholders, this study was restricted in computational power from generating a realistic population size, for example the 865,000 smallholders estimated to be in Ghana. Further work in this area where a larger computational capacity is available could investigate how larger simulated sample sizes affect the results presented in this paper.

This model, though rooted in the existing literature, remains a toy, and may be hindered by variables missing or omitted from the final specification which could prevent its predictions from capturing the true welfare effects of an intervention. Omitted variable bias in the empirical welfare investigation may lead to an overestimation of the included variables, as they absorb the effect of the omitted. Alongside this, unobservable variables that affect welfare, such as cultural or ethno-religious strife, which has proven important in investigations into cocoa smallholders' welfare (Maguire-Rajpaul et al., 2021), could not be included into the model at this stage. This presents a final opportunity for future work to tailor such a model to the cultural needs of individuals, helping to more accurately capture subjective elements of welfare.

9. Concluding Remarks

The model output, an average of 30 trials of an agent-based simulation of 100 individual West African smallholder cocoa farmers' profits, and subsequent deforestation values, is statistically viable as validated by comparison to household survey data from Yahaya et al. (2015) and Laven, Bymolt and Tyszler (2020). I establish a proportional connection between farm profit and deforestation, such that a 1 US$ increase in profit is associated, on average, with a 0.000060945 ha increase in deforestation in the subsequent period.

This has allowed inferences to be drawn about welfare. Based on these findings, there exists a mechanism in which there are decreasing returns to farm profit on welfare, due to the reduction in access to environmental services. Maximum values of profit at varying degrees of population concentration lie within reachable distance to current average profit levels. It becomes

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evident that interventions into cocoa smallholder welfare in West Africa should be reevaluated, shifting away from those which seek to solely improve farm profit, such as subsidies or crop-price increases, or targeting higher levels of technical efficiency without direction to focus this on bettering the productivity of existing land, rather than expansion.

In sum, my findings suggest that profit-targeting interventions are constrained in improving smallholder welfare and have the capacity to become detrimental at larger scales. My model argues the case for prioritising the education of smallholders, which on average is junior level, but which holds the highest positive weight in the welfare function. Alternatively, bettering food security, and providing alternative forms of income such as cash transfers, may have a net positive effect on welfare without detriment to the environment or to neighbouring smallholders' welfare outcomes. Together, these interventions hold the potential to reestablish smallholders at the centre of their own welfare and mitigate conflict and disillusionment that may arise with the detachment of welfare and income.

This returns to the multi-environmentalities framework explored in Maguire-Rajpaul et al. (2021), where the authors criticize the use of top-down governance, including subsidies, on West African cocoa smallholders. Such methods marginalise smallholder voices and perpetuate long-entrenched power asymmetries in cocoa farming regions. Therefore, it may well be the case that targeting non-income-based interventions when considering climate-safe cocoa production may not only improve objective welfare, as I posit, but also improve subjective measures of welfare, such as the autonomy and empowerment of smallholder cocoa farmers.

Overall, this paper and its findings may be used as a reference to consider the impacts of planned interventions on populations of smallholders within the West African cocoa producing regions. Though not a replacement for field investigations and real smallholder-level data, the model serves as a tool for tentative evaluations, especially in the absence of comprehensive data.

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References

Abokyi, E., Strijker, D., Asiedu, K.F. and Daams, M.N. (2020). The impact of output price support on smallholder farmers' income: evidence from maize farmers in Ghana. Heliyon, 6(9), p.e05013. doi:https://doi.org/10.1016/j.heliyon.2020.e05013.

Abukari, A.-B.T., Zakaria, A. and Azumah, S.B. (2022). Gender-based participation in income generating activities in cocoa growing communities. The role of youth training programs. Heliyon, 8(2), p.e08880. doi:https://doi.org/10.1016/j.heliyon.2022.e08880.

Agbonlahor, M.U., Adewuyi, S.A. and Ogundairo, V.O. (2015). Do Rural Smallholder Farmers Subsidize Farm Investments With Non-farm Income? A Study of Vegetable Farmers. International Journal of Vegetable Science, 22(3), pp.231–242. doi:https://doi.org/10.1080/19315260.2015.1020464.

Anderman, T.L., Remans, R., Wood, S.A., DeRosa, K. and DeFries, R.S. (2014). Synergies and tradeoffs between cash crop production and food security: a case study in rural Ghana. Food Security, [online] 6(4), pp.541–554. doi:https://doi.org/10.1007/s12571-014-0360-6.

Andersen, L.E., Groom, B., Killick, E., Ledezma, J.C., Palmer, C., Weinhold, D., Bilge, U. and Gutierrez, D. (2015). Modelling Land Use, Deforestation, and Policy: A Hybrid Optimisation-Heterogeneous Agent Model with Application to the Bolivian Amazon. Centre for Climate Change Economics and Policy Working Paper No. 186. [online] Available at: https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2014/09/Working-Paper-164-Andersen-et-al-2015.pdf.

Asitoakor, B.K., Vaast, P., Ræbild, A., Ravn, H.P., Eziah, V.Y., Owusu, K., Mensah, E.O. and Asare, R. (2022). Selected shade tree species improved cocoa yields in low-input agroforestry systems in Ghana. Agricultural Systems, 202, p.103476. doi:https://doi.org/10.1016/j.agsy.2022.103476.

ATTIPOE, S.G., CAO, J., OPOKU-KWANOWAA, Y. and OHENE-SEFA, F. (2021). Assessing the impact of non-governmental organization's extension programs on sustainable cocoa production and household income in Ghana. Journal of Integrative Agriculture, 20(10), pp.2820–2836. doi:https://doi.org/10.1016/s2095-3119(21)63607-9.

Berry, B.J.L., Kiel, L.D. and Elliott, E. (2002). Adaptive agents, intelligence, and emergent human organization: Capturing complexity through agent-based modeling. Proceedings of the National Academy of Sciences, [online] 99(Supplement 3), pp.7187–7188. doi:https://doi.org/10.1073/pnas.092078899.

Besseah, F.A. and Kim, S.H. (2014). TECHNICAL EFFICIENCY OF COCOA FARMERS IN GHANA. Journal of Rural and Development, [online] 37(2), pp.159–182. doi:https://doi.org/10.22004/ag.econ.196615.

Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R. and Ziervogel, G. (2005). Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463), pp.2183–2194. doi:https://doi.org/10.1098/rstb.2005.1742.

Butler, R.A. (2013). Forest data: Ghana Deforestation Rates and Related Forestry Figures. [online] Mongabay.com. Available at: https://worldrainforests.com/deforestation/forest-information-archive/Ghana.htm [Accessed 31 Mar. 2025].

Carpantier, J.-F. and Sapata, C. (2015). Empirical welfare analysis: when preferences matter. Social Choice and Welfare, 46(3), pp.521–542. doi:https://doi.org/10.1007/s00355-015-0927-y.

COCOBOD (2024). REVIEW OF THE PRODUCER PRICE OF COCOA FOR THE 2024/2025 COCOA SEASON WEDNESDAY, 11TH SEPTEMBER, 2024. [online] Cocobod.gh. Available at: https://cocobod.gh/news/review-of-the-producer-price-of-cocoa-for-the-20242025-cocoa-season-wednesday-11th-september-2024.

Danso-Abbeam, G. and Baiyegunhi, L.J.S. (2020). Do farm-level technical efficiency and welfare complement each other? Insight from Ghana's cocoa industry. Journal of Economic Structures, 9(1). doi:https://doi.org/10.1186/s40008-020-00200-w.

Edwards-Jones, G. (2006). Modelling farmer decision-making: concepts, progress and challenges. Animal Science, 82(6), pp.783–790. doi:https://doi.org/10.1017/asc2006112.

Fairtrade Foundation (2022). Cocoa farmers. [online] Fairtrade Foundation. Available at: https://www.fairtrade.org.uk/farmers-and-workers/cocoa/.

Fairtrade Foundation (2025). Farmers and Workers, Kuapa Kokoo, Ghana. [online] Fairtrade Foundation. Available at: https://www.fairtrade.org.uk/farmers-and-workers/cocoa/kuapa-kokoo-ghana/.

FAO (2024). Statistics. [online] Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/statistics/en/.

Giller, K.E., Delaune, T., Silva, J.V., van Wijk, M., Hammond, J., Descheemaeker, K., van de Ven, G., Schut, A.G.T., Taulya, G., Chikowo, R. and Andersson, J.A. (2021). Small farms and development in sub-Saharan Africa: Farming for food, for income or for lack of better options? Food Security, 13. doi:https://doi.org/10.1007/s12571-021-01209-0.

Glewwe, P. (1991). Investigating the determinants of household welfare in Côte d'Ivoire. Journal of Development Economics, 35(2), pp.307–337. doi:https://doi.org/10.1016/0304-3878(91)90053-x.

Glover, D.J. (1984). Contract farming and smallholder outgrower schemes in less-developed countries. World Development, 12(11-12), pp.1143–1157. doi:https://doi.org/10.1016/0305-750x(84)90008-1.

Gómez-Limón, J.A., Gutiérrez-Martín, C. and Riesgo, L. (2016). Modeling at farm level: Positive Multi-Attribute Utility Programming. Omega, 65, pp.17–27. doi:https://doi.org/10.1016/j.omega.2015.12.004.

Hasell, J. (2022). From $1.90 to $2.15 a day: the updated International Poverty Line. [online] Our World in Data. Available at: https://ourworldindata.org/from-1-90-to-2-15-a-day-the-updated-international-poverty-line.

Hashmiu, I., Agbenyega, O. and Dawoe, E. (2022). Cash crops and food security: evidence from smallholder cocoa and cashew farmers in Ghana. Agriculture & Food Security, 11(1). doi:https://doi.org/10.1186/s40066-022-00355-8.

IDH (2018). How we're making a difference -Côte d'Ivoire How we're making a difference for cocoa farmers and cooperatives in Côte d'Ivoire. [online] Available at: https://www.idhsustainabletrade.com/uploaded/2018/05/How-IDH-is-making-a-difference-smallholder-inclusion-cocoa.pdf.

International Cocoa Initiative (2017). Cocoa farmers in Ghana experience poverty and economic vulnerability | ICI Cocoa Initiative. [online] www.cocoainitiative.org. Available at: https://www.cocoainitiative.org/news/cocoa-farmers-ghana-experience-poverty-and-economic-vulnerability.

Jayne, T.S., Chamberlin, J. and Milu Muyanga (2012). Emerging Land Issues in African Agriculture: Implications for food security and poverty reduction strategies. [online] Center on Food Security and the Environment. Available at: https://fse.fsi.stanford.edu/publications/emerging_land_issues_in_african_agriculture_implications_for_food_security_and_poverty_reduction_strategies [Accessed 19 Dec. 2024].

Kalischek, N., Lang, N., Renier, C., Daudt, R.C., Addoah, T., Thompson, W., Blaser-Hart, W.J., Garrett, R., Schindler, K. and Wegner, J.D. (2023). Cocoa plantations are associated with deforestation in Côte d'Ivoire and Ghana. Nature Food, [online] 4(5), pp.384–393. doi:https://doi.org/10.1038/s43016-023-00751-8.

Karsenty, A. and Salau, S. (2023). Fiscal incentives for improved forest management and deforestation-free agricultural commodities in Central and West Africa. International Forestry Review, [online] 25(1), pp.27–38. doi:https://doi.org/10.1505/146554823836838691.

Kimball, M.S., Ohtake, F., Reck, D.H., Tsutsui, Y. and Zhang, F. (2015). Diminishing Marginal Utility Revisited. SSRN Electronic Journal, [online] (Working Paper 32077). doi:https://doi.org/10.2139/ssrn.2592935.

Kirioua, A.J. and Brüntrup, M. (2023). Unintended risks for smallholder in the Global South? Example of the cocoa sector in Côte d'Ivoire. [online] Idos-research.de. Available at: https://www.idos-research.de/en/the-current-column/article/unintended-risks-for-smallholder-in-the-global-south-example-of-the-cocoa-sector-in-cote-divoire/.

Knudsen, M.H. (2007). Making a living in the cocoa frontier, Western Ghana: Diversifying incomes in a cocoa economy. Geografisk Tidsskrift-Danish Journal of Geography, 107(2), pp.29–44. doi:https://doi.org/10.1080/00167223.2007.10649567.

Laven, A. and Boomsma, M. (2012). Incentives for sustainable cocoa production in Ghana : moving from maximizing outputs to optimizing performance. [online] Royal Tropical Institute. Available at: https://www.researchgate.net/publication/254811154_Incentives_for_sustainable_cocoa_production_in_Ghana_moving_from_maximizing_outputs_to_optimizing_performance.

Laven, A., Bymolt, R. and Tyszler, M. (2018). Demystifying the cocoa sector in Ghana and Côte d'Ivoire. Harvard Dataverse, [online] V2. doi:https://doi.org/10.7910/dvn/82twzj.

Laven, A., Bymolt, R. and Tyszler, M. (2020). Demystifying the Cocoa Sector in Ghana and Côte d'Ivoire. [online] KIT Royal Tropical Institute. Available at: https://www.researchgate.net/publication/341463804_Demystifying_the_Cocoa_Sector_in_Ghana_and_Cote_d.

Lim, C., Waldron, D. and Wayne, C. (2024). *Planting the seeds of impact: the investment potential of African agriculture in ten charts*. [online] Acumen. Available at: https://acumen.org/blog/planting-the-seeds-of-impact-the-investment-potential-of-african-agriculture-in-ten-charts/.

Maguire-Rajpaul, V.A., Sandbrook, C., McDermott, C. and Hirons, M.A. (2021). Climate-smart cocoa governance risks entrenching old hegemonies in Côte d'Ivoire and Ghana: a multiple environmentality analysis. Geoforum, 130. doi:https://doi.org/10.1016/j.geoforum.2021.09.015.

Meyfroidt, P. (2018). Trade-offs between environment and livelihoods: Bridging the global land use and food security discussions. Global Food Security, [online] 16, pp.9–16. doi:https://doi.org/10.1016/j.gfs.2017.08.001.

Mortimer, R., Saj, S. and David, C. (2017). Supporting and regulating ecosystem services in cacao agroforestry systems. Agroforestry Systems, 92(6), pp.1639–1657. doi:https://doi.org/10.1007/s10457-017-0113-6.

Ohlsson, L. (2000). Livelihood Conflicts: Linking poverty and environment as causes of conflict. [online] Sida. Available at: https://www.sida.se/en/about-sida/publications-archive/livelihood-conflicts-linking-poverty-and-environment-as-causes-of-conflict.

Opatz, C.P. (2020). From Bean to Bar An assessment of chocolate producing companies advancements towards closing the living income gap of smallholder cocoa farmers. [online] studenttheses.uu.nl. Available at: https://studenttheses.uu.nl/handle/20.500.12932/35531.

Reardon, T., Crawford, E. and Kelly, V. (1994). Links between Nonfarm Income and Farm Investment in African Households: Adding the Capital Market Perspective. American Journal of Agricultural Economics, 76(5), p.1172. doi:https://doi.org/10.2307/1243412.

Ruf, F., Schroth, G. and Doffangui, K. (2014). Climate change, cocoa migrations and deforestation in West Africa: What does the past tell us about the future? Sustainability Science, 10(1), pp.101–111. doi:https://doi.org/10.1007/s11625-014-0282-4.

Ruf, F.O. and Burger, K. (2018). Planting and Replanting Tree crops Small holders' investment decision. [online] ResearchGate. Available at: https://www.researchgate.net/publication/242269471_Planting_and_Replanting_Tree_crops_Small_holders%27_investment_decision [Accessed 1 Apr. 2025].

Ruml, A., Ragasa, C. and Qaim, M. (2021). Contract farming, contract design and smallholder livelihoods*. Australian Journal of Agricultural and Resource Economics, 66(1), pp.24–43. doi:https://doi.org/10.1111/1467-8489.12462.

Schneider, M., Winchester, C., Goldman, E. and Shao, Y. (2023). Mapping Cocoa and Assessing Deforestation Risk for the Cocoa Sector in Côte d'Ivoire and Ghana. World Resources Institute. doi:https://doi.org/10.46830/writn.21.00011.

Selorm, A., Sarpong, D.B.S., Egyir, I.S., Bonsu, A.M. and An, H. (2023). Does contract farming affect technical efficiency? Evidence from soybean farmers in Northern Ghana. Agricultural and Food Economics, [online] 11(1), p.undefined–undefined. doi:https://doi.org/10.1186/s40100-022-00240-9.

Simons, L. (2015). Changing the Food Game: Market Transformation Strategies for Sustainable Agriculture. [online] Greenleaf Publishing. Available at: https://www.routledge.com/Changing-the-Food-Game-Market-Transformation-Strategies-for-Sustainable-Agriculture/Simons/p/book/9781783532308?srsltid=AfmBOooLDtgyV8EZxnlYES2ohqqhZ1oJybcI0bhhU_e8LiR_74OVqP-B.

Tawiah, A. (2024). The Ghana Cocoa Report 2024: Ghana Cocoa Crop Seasons: A Comprehensive Analysis. [online] Anangtawiah.com. Available at: https://anangtawiah.com/articles/details/The%20Ghana%20Cocoa%20Report%202024:%20Ghana%20Cocoa%20Crop%20Seasons:%20A%20Comprehensive%20Analysis-213 [Accessed 15 Mar. 2025].

UNEP-WCMC (2024). UN Environment Programme World Conservation Monitoring Centre. [online] UNEP-WCMC. Available at: https://www.unep-wcmc.org/en.

UNESCO (2021). UNESCO Institute for Statistics (UIS). [online] Unesco.org. Available at: https://databrowser.uis.unesco.org/ [Accessed 30 Apr. 2025].

van Schoonhoven, M. (2021). How Fairtrade Impacts the West African Cocoa Industry | Ask the Expert. [online] www.foodunfolded.com. Available at: https://www.foodunfolded.com/article/how-fairtrade-impacts-the-west-african-cocoa-industry-ask-the-expert.

Villar, A. (2023). Journal of Human Development and Capabilities A Multi-Disciplinary Journal for People-Centered Development Welfare Poverty Measurement. *Journal of Human Development and Capabilities*. [online] doi:https://doi.org/10.1080/19452829.2023.2199974.

Voukelatou, V., Gabrielli, L., Miliou, I., Cresci, S., Sharma, R., Tesconi, M. and Pappalardo, L. (2020). Measuring objective and subjective well-being: dimensions and data sources. International Journal of Data Science and Analytics, [online] 11(11). doi:https://doi.org/10.1007/s41060-020-00224-2.

Waarts, Y.R., Janssen, V., Aryeetey, R., Onduru, D., Heriyanto, D., Aprillya, S.T., N'Guessan, A., Courbois, L., Bakker, D. and Ingram, V.J. (2021). Multiple pathways towards achieving a living income for different types of smallholder tree-crop commodity farmers. Food Security, 13(6), pp.1467–1496. doi:https://doi.org/10.1007/s12571-021-01220-5.

Waarts, Y.R., Janssen, V., Ingram, V.J., Slingerland, M.A., F.C. van Rijn, Beekman, G., Just Dengerink, Vliet, J.A. van, E.J.M.M. Arets, Sassen, M., W.J. Guijt and S.M. van Vugt (2019). A living income for smallholder commodity farmers and protected forests and biodiversity: how can the private and public sectors contribute? : White Paper on sustainable commodity production. [online] Library.wur.nl. Available at: https://library.wur.nl/WebQuery/wurpubs/556298 [Accessed 21 Dec. 2024].

Wentworth, A. (2024). Can the rising cost of chocolate help cocoa producers go green? [online] Climate Home News. Available at: https://www.climatechangenews.com/2024/05/23/can-the-rising-cost-of-chocolate-help-cocoa-producers-go-green/.

Williams, R. (2020). Heteroskedasticity. [online] University of Notre Dame. Available at: https://www3.nd.edu/~rwilliam/stats2/l25.pdf.

Willock, J., Deary, I.J., Edwards-Jones, G., Gibson, G.J., McGregor, M.J., Sutherland, A., Dent, J.B., Morgan, O. and Grieve, R. (1999). The Role of Attitudes and Objectives in Farmer Decision Making: Business and Environmentally-Oriented Behaviour in Scotland. Journal of Agricultural Economics, 50(2), pp.286–303. doi:https://doi.org/10.1111/j.1477-9552.1999.tb00814.x.

World Bank (2024). World Bank Group - World Development Indicators. [online] Worldbank.org. Available at: https://www.worldbank.org/ext/en/home [Accessed 27 Nov. 2024].

Yahaya, A., Karli, B., Gül, M. and Karli, B. (2015). Economic analysis of cocoa production in Ghana: the case of eastern region. [online] Available at: http://www.custoseagronegocioonline.com.br/numero1v11/OK_18_cocoa.pdf.

Appendix

Appendix A: Derivation of l_f^{F*}

$$The\ fixed\ relationship\ between\ land\ and\ labour\ is\ such\ that\ the\ marginal\ cost,\ in\ labour,\ of\ an\ additional\ hectare\ of\ land\ is\ determined\ by$$

$$\frac{dl^F}{dH} = (1+q)H$$

$$Allowing\ for\ an\ expression\ of\ H\ to\ be\ found\ via\ integration\ on\ the\ above\ expression$$

$$l^F = \int (1+q)H$$ From this we rearrange to express the equation in terms of l^F for the purpose of optimisation

$$l^F = \frac{(1+q)}{2}H^2$$

$$H = (\frac{2l^F}{1+q})^{0.5}$$

$$Using\ Lagrangian\ Optimisation, we\ maximise\ Z_f\ subject\ to\ H$$

$$Maximise\ Z_f\ subject\ to\ H = (\frac{2l^F}{1+q})^{0.5}$$

$$L(l^F, H, \lambda): p(AH) - w(l^F) - \lambda((\frac{2l^F}{1+q})^{0.5} - H)$$

$$Evaluating\ the\ first\ order\ conditions\ such\ that$$

$$\nabla L = 0$$

$$then$$

$$\frac{dL}{dl^F} = -w - \lambda(\frac{2^{0.5}}{2(1+q)^{0.5}})(l^F)^{-0.5} = 0$$

$$\frac{dL}{dH} = pA + \lambda = 0$$

$$\lambda = -pA$$

$$Using\ this\ result\ to\ solve\ for\ l^F: \quad pA(\frac{2^{0.5}}{2(1+q)^{0.5}})(l^F)^{-0.5} = w$$

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$$\frac{\sqrt{2}pA}{2w\sqrt{1+q}} = \sqrt{l^F}$$

$$\frac{(pA)^2}{2w^2(1+q)} = l^F$$

$$l_f^{F*} = \frac{0.5(Ap_f)^2}{w_f^2(1+q_f)}$$

$$Note\ that\ this\ is\ expressed\ in\ Andersen\ et\ al.(2015)\ as\ its\ equivalent, \left(\frac{(1+q)w}{Ap}\right)^{-2}\frac{(1+q)}{2}$$

Appendix B: Regression Variable Specification and Summary Statistics

OLS regression estimates				
Variable	**Variable in Data Source**	**Description**	**Mean**	**Std. Dev.**
Welfare	*PPI_250dollar-day*	*"Likelihood of being under $2.50/day PPP 2005". The negation is taken by computing (-1)*PPI_250dollar-day*	44.4364	31.16934
Profit from Cocoa	*cocoa_profit1_usdha*	*"Revenues minus inputs (US$/ha)"*	648.061	407.0745
Land Owned	*all_land_owned_ha*	*"All land owned (ha)"*	5.78971	5.247653
Food Security	*foodsec6*	*"Meals per day: June"*	2.604995	0.536383
Environmental Services	*cocoa_pest_hi_cost*	*"Median daily rate (comparable region) for a hired labourer for pesticide application". The negation is taken by computing (-1)*cocoa_pest_hi_cost. We convert this to US$ within the model.*	1767.506	1860.411
Other Income Sources	*n_hh_incomes*	*"Number of different household sources of incomes"*	2.493596	0.995906
Education	*p1_respondent_education*	*"Respondent: education level"; 0=no formal, 1=primary, 2=junior high, 3=senior high, 4=university, 5=technical college, 6=other.*	1.376355	1.234988
Number of Household Members	*hhmem_number*	*"Number of household members living in the compound"*	6.264314	3.200178
Data Source: Laven, Bymolt and Tyszler (2018)				
*In Section 6.2, Laven, A., Bymolt, R. and Tyszler, M. (2020) and (Anderman et al., 2014) also inform variable means.				

Appendix C: STATA Output Regression Heteroskedasticity Test

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. estat hettest

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of log_welfare

H0: Constant variance

    chi2(1) = 148.22
Prob > chi2 = 0.0000

.
```


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