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Measurement of the impact of buffer stock intervention on food security of smallholder farmers in Ghana by means of the nutrient-content household dietary diversity index

Emmanuel Abokyi^{1*} and Kofi Fred Asiedu²

Abstract: Buffer stock intervention is a hedging policy against income losses due to price fluctuations, primarily from farming activities, notably the production of cereals. This paper investigates the impact of buffer stock intervention on smallholder farmers' food security in Ghana. To this end, the motivation was to estimate the nutrient-content household dietary diversity index (NHDDI) based on a cross-sectional data set. We apply Coarsened Exact Matching, Weighted Least Squares, and Weighted Ordered Probit analysis as econometric methods. We find that marital status, gender, education, and income positively impact food security, while the household size and the number of children under five years old have a negative impact. We also find that income and education, which have a positive direct impact on food security, have a mitigating effect on the negative impact of children

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under five years. The most important finding is that participation in the buffer stock operations improves the household food security of participating smallholder farmers. NAFCO in its present form has positive effects on food security for participants, positive but smaller price effects for non-participating smallholder farmers, and negative effects for consumers at large. The latter effect could be reduced by implementing a buffer stock policy consisting of buying during the glut and selling when supply is tight.

Subjects: Rural Development; Economics and Development; Research Methods in Development Studies

Keywords: Food security; buffer stock operation; nutrient-content household dietary diversity index (NHDDI); coarsened exact matching; ordered probit model; Ghana

1. Introduction

For decades, food security has been a development goal and recognized as a fundamental human right in recent years. Article 25 of the United Nations Universal Declaration of Human Rights states that “everyone has the right to a standard of living adequate for themselves and their family’s health and wellbeing” (Rukundo et al., 2014). Food security is especially critical for low-income families, who spend a substantial proportion of their income on food (Kirkland et al., 2013). Nutrient deficiency and poor diets can ignite health problems and cause havoc, especially in low-income countries amid pandemics, such as COVID-19 (O’Hara & Toussaint, 2021).

Initially, food security focused on the availability of basic foodstuffs. However, the concept has gradually become more comprehensive to include food distribution and consumer choice. It relates to macro and micronutrients (Headey & Ecker, 2013). The former are nutrients needed in large quantities (e.g., carbohydrates, proteins, and lipids), the latter are nutrients required in small amounts, such as vitamins and minerals (Warne, 2014).

Currently, the literature distinguishes the following four components of food security: availability, access, utilization, and stability (Carletto et al., 2013). Availability is a macro geographical dimension relating to the supply of food determined by domestic production, trade, food stocks, and food aid. It captures the food sufficiency of a country or a specific geographic area. Access to food has a micro-and macroeconomic geographical dimension. The former comprises the economic, physical, or social barriers to households, especially purchasing power and food prices (Moroda et al., 2018). The macro dimension relates to pricing barriers resulting from inflation, price volatility, market and transportation systems deficiencies, at the community, regional, national, or global level (Leroy et al., 2015). Utilization is a micro geographical dimension and concerns food intake that meets dietary needs for good health. It comprises individual and household level consumption of macro and micronutrients, the knowledge of food nutrients, and care techniques (Coates, 2013). It also includes food safety and the conditions under which it is processed or prepared. Finally, the macro geographical component stability implies that food security is not a seasonal but a permanent characteristic (Noack & Pouw, 2015).

To ensure all four components of food security are available to citizens, governments have instituted policies such as buffer stock intervention to mitigate price instability in failed markets (Devereux, 2016; P. L. Kennedy et al., 2018; Poulton et al., 2006). Usually, buffer stock interventions are intended to regulate agricultural commodity output in a bid to stabilize food prices to stay within a price band to benefit farmers or consumers (Abokyi et al., 2018; Demeke et al., 2008; Poulton et al., 2006). The band is between the floor and ceiling price set by the government (HLPPE, 2011). To this end, the government procures excess production into public warehouses and stores it till market prices increase above the floor prices. When market prices go above or near the

ceiling price, the government releases public storage into the domestic economy to depress prices by increasing market supply (Pu & Zheng, 2018).

Buffer stock policies have been used by both developed and developing countries. In the United States in the 1990s, under the Commodity Credit Corporation (CCC) program, the government bought wheat stocks to prevent prices from falling below the loan rate (P. L. Kennedy et al., 2018). Also, under the Common Agricultural Policy (CAP) of the European Union, buffer stocks interventions were implemented by the European Commission/Union (EU) in the 1980s to support farmers through price stabilization of various outputs (McClintock, 2021). Countries like India and China also used buffers stocks to stabilize markets in the past, with rice and maize as key outputs (Pu & Zheng, 2018). In developing countries, buffer stock operations usually target grains due to their non-perishability and the importance of grains to the food budgets of poor households.

Evaluations studies on the impacts of buffer stock operations have focused on price and income stabilization and thus have received due attention in the literature. For instance, in the case of the USA, the implementation of buffer stock policy was found to lead to price stability and increased production, as farmers were assured of revenues from their investment (Just & Gardner, 1981, 1981; P. L. Kennedy et al., 2018). (Fujita, 2010) found that in India in the 1970s, buffer stock policy under the Green Revolution led to price stabilization, improving food production in general and food self-sufficiency. For the EU in the 1980s (P. L. Kennedy et al., 2018), found that implementing price support via buffer stocks under the CAP led to over-production in those countries. However, it is known that increased production may not necessarily leads to increased food security; especially all the dimensions.

To the best of our knowledge, even though food security and food buffer stocks have received much attention in literature, establishing the causal relationship between food buffer stocks and food security vis-a-viz estimating the causal impact of buffer stock policy on farmers' food security in Ghana is an under-researched topic. In addition, the World Food Programme reports that 3.6 million people in Ghana, representing about 10 percent of the population are food insecure. Also, 18.6 percent of the rural Ghanaian population are food insecure (WFP, 2020). Thus, critical attention is needed to be given to policies and interventions that are implemented to improve food security. Yet, studies focusing on the casual assessment of impacts of buffer stock policies on food security are limited in Ghana other developing countries.

The present paper intends to fill this gap by comparing food security for participating and non-participating smallholder farmers in the Ghanaian public buffer stock program, NAFCO. To this end, our motivation is to estimate the nutrient-content household dietary diversity index (NHDDI), as a food security measure, for both participants and non-participants based on a cross-sectional data set. The basic question that guides our analysis is: how has the buffer stock policy impacted on the food security of participating households? This study contributes to the development of an improved metric (NHDDI) for the measurement of food security at the household level. It also contributes to providing literature on empirical evidence on casual impacts of buffer stock and household food security.

The remainder of the paper is organized as follows. Section 2 presents a brief overview of buffer stock intervention in Ghana. Section 3 summarizes the NHDDI and the literature on the determinants of food security applied to cereals or rice-producing smallholder farmers in Ghana. Section 4 discusses the data and the estimation strategy. The empirical results are presented in Section 5, and the conclusion and policy implications are discussed in Section 6.

2. Public buffer policy in Ghana

Managing agricultural price instability continue to be a concern for policy makers all over the world (De & Singh, 2022). Generally, price instability can be managed either by reducing the level of instability or its effects can be buffered. Either way, the approach can be implemented through

market-based strategies or public interventions (Galtier, 2013). These two approaches often require some kind of hedging against price fluctuation risk. Hedging in agricultural market often involves price risk management whereby producers and consumers of an agricultural commodity attempt to offset exposure to price fluctuations of the underlying interest in some opposite position in another market. Thus, hedgers will minimize their prices risk while speculators will rather maximize profits from the risk underlying's nature by predicting market movements (Cabrera & Schulz, 2016). The causal relationship between commodity futures and commodity prices is known to worsen food security, it is important to hedge against short-term favourable price movements by using buffer stock policy. Agricultural commodity buffer stock policy in a market intervention that hedge farmers against income and price uncertainty (Trollman et al., 2023).

The National Buffer Stock Programme (NAFCO) in Ghana was launched in 2010. Its overall objective is to insulate smallholder farmers against income losses due to low prices for their produce, provide them with an assured income, improve production by stimulating the expansion of agricultural land and inputs usage, and improve farmers' food security and wellbeing (Benin et al., 2013). In addition, the policy aimed to provide food security for consumers and stimulate economic growth. NAFCO stabilizes cereal prices for smallholder farmers, mainly to reduce annual gluts characterizing the production. It also provides market access for farmers at the farm gate with remunerative prices (Abokyi, 2021)

NAFCO purchases produce at a fixed price, called the NAFCO price, set by the government above the open market price. The NAFCO price is set annually. Purchases by NAFCO generally happen during the harvesting period (glut) when prices of cereals are low in the open market. The NAFCO price is based on the average cost of producing the relevant crop at different farms, plus a 15% profit margin (Benin et al., 2013). Though there are spatial differences in the production cost due to local production conditions, such as soil quality, distance to the market, and market conditions, these differences do not affect the price set by NAFCO. The program uses licensed buying companies (LBCs) to procure maize and rice at the farm gate from smallholder farmers in remote rural communities in six regions of the country. The purchases made by the LBCs are sent to the nearest warehouses of the program for preservation and storage. NAFCO pays the LBCs on a commission basis (Abokyi et al., 2018). Participation in the program is free of charge to all smallholder farmers.

The NAFCO program does not release its storage into the domestic economy but sells it to institutions including secondary schools under the Free Senior High School Programme, hospitals, the army, prisons, and poultry¹ farmers. These institutions usually purchase maize or rice in large volumes, impacting prices in the open market. When NAFCO takes volumes out of the open market, it reduces the open market volume, positively impacting the price. This helps keep the open market price of the produce above the targeted lower band (Benin et al., 2013). In contrast to general buffer stocks operations with two interventions (buying during the glut and releasing stocks to the open market when there is scarcity), NAFCO only intervenes once (buying) when prices fall below the lower band. There is no release of stocks into the open market. The selling of stock by NAFCO is to institutions but not households.

NAFCO intervention (and buffer stock intervention in general) impacts participating farmers' food security in several ways. First, through increased income. NAFCO increases income for participants by fixing the minimum price based on production² costs plus a 15% makeup (Benin et al., 2013). The price thus set by NAFCO is substantially higher than the glut market price. The higher income enables farmers to acquire more diverse foods such as protein and vegetables that they may not grow (Ogundari, 2017; Vellema et al., 2016). In addition, NAFCO lowers transaction costs by eliminating middlemen, leading to higher revenues (Abokyi et al., 2021). Secondly, NAFCO stabilizes the prices the participants receive for their produce (Benin et al., 2013) such that they have a stable income all-year-round to the benefit of food security. Third, NAFCO reduces uncertainty

and risk in cereal markets, thus reducing the need for farmers to hedge against low prices during the glut period. The higher and more stable income and the reduction of risk have multiple impacts, ranging from investment in the production of more cereals or other products (Kaminitz 2019 (Abokyi et al., 2020, 2021); to the purchase of non-food goods and food thereby improving dietary diversity (Bailey, 2013; Codjoe et al., 2016; Kc et al., 2018). Finally, NAFCO intervention saves farmers time because they no longer need to travel to markets to sell their produce. This applies especially to women, who often are the key actors in the marketing of agricultural produce in Africa (Haile et al., 2012). The time saved can be spent on various activities, including producing other crops such as vegetables or rearing small ruminants, improving a farmer's food security (Razaque & Hassa, 2013).

3. The nutrient-content household dietary diversity index (NHDDI) and the determinants of household dietary diversity

There is no commonly agreed "golden standard" of food security measurement because of the concept's complex multidimensional nature (Leroy et al., 2015; Ogundari, 2017). In particular, it is challenging to capture all the dimensions of food security using a single index (Carletto et al., 2013). Thus, various methodological approaches and indices differ by the dimensions they measure, i.e., access, utilization, availability, and stability (Jones et al., 2013; Leroy et al., 2015).

The household dietary diversity index (HDDI) is one of the most common indices for measuring food security. It measures the extent of the variety of the food items consumed by a household over a given period (Andriamparany et al., 2021; (Muthini et al., 2020; Ogundari, 2017). It considers the consumption of 12 groups of food items (see Table 1, panel a) and measures two dimensions of food security: utilization and access (G. Kennedy et al., 2011; Ogundari, 2017). The NHDDI is based on a standardized questionnaire that is simple and easy to understand by both enumerators and respondents (Swindale & Bilinsky, 2006), which facilitates data collection in a relatively short period. The sum of the food groups consumed, i.e., a higher index, indicates more security (Kiboi et al., 2017). The HDDI is generally applied for evaluating project and policy interventions (see (Verger et al., 2019).

(Vellema et al., 2016) and (Zhang et al., 2017) amongst others, have documented several drawbacks of the HDDI. One drawback is the 24-hour reference (recall) period. This restriction implies that the true dietary diversity may be underestimated because food groups that are frequently, but not daily, consumed are not captured. To overcome this problem in this study, we increase the recall period to one week immediately preceding the interview date. Another weakness of the HDDI is that it ignores cultural differences. However, in the present study, cultural differences play a minor role given the limited geographical scope. Finally, the most critical limitation of the HDDI is that the food groups are not weighted based on their nutrient and health impacts. For example, the weight of coffee is equal to the weight of cereals or fruits and vegetables. These food groups are taken to have equal nutrient value. To overcome this problem, we construct a new index, the nutrient-content household dietary diversity index (NHDDI), which stratifies the HDDI food groups into five categories based on nutrient content. The five NHDDI categories are (1) low, (2) basic, (3) moderate, (4) adequate, and (5) high. See Table 1, panel b. A higher category comprises all the lower categories. For instance, moderate comprises the HDDI group 1–7. Hence, the higher the NHDDI level, the higher the food security level. Note that the NHDDI does not consider the quantity of each food item a household consumes nor the distribution of the consumption of the food items among the household members (Upton et al., 2016).

3.1. Determinants of household dietary diversity

The literature discusses several variables that impact dietary diversity (as a measure of food security), including household income, household size, gender of the household head, education, age, and marital status. Below, we discuss the above determinants and participation in the NAFCO and their expected impacts on NHDDI.

Table 1. The HDDI food groups (a) and the NHDDI categories (b)

The HDDI Food groups (a)			
1	Cereals	7	Eggs
2	Roots and Tubers	8	Fish and seafood
3	Oils and fats	9	Pulses, legumes (pigeon pea)
4	Vegetables	10	Milk and milk products
5	Fruits (e.g., mango, papaya,)	11	Sugar and honey
6	Meat (e.g., beef, poultry, .)	12	Miscellaneous (tea, coffee, cake)
The NHDDICategories (b)			
Category (Level)	Nutrient-content	NHDDI Food groups	HDDI groups
1	Low	roots & tubers, cereals, and fat & oil	1–3
2	Basic	level 1 plus vegetables and fruits	1–5
3	Moderate	level 2 plus meat, fish, and seafood	1–7
4	Adequate	level 3 plus pulse and legumes, eggs, milk, and milk products,	1–10
5	High	level 4 plus sugar, honey, and miscellaneous	1–12

Sources: Modified from (Kiboi et al., 2017; Mekuria et al., 2017)

Household income as a determinant of household dietary diversity dates back to Bennett's law (Bennett, 1941) which states that increased purchasing power enables households to partly switch from starch-dominated diets to more varied diets, including vegetables, fruits, dairy products, and meat (Bennett, 1941; Vellema et al., 2016). (Codjoe et al., 2016; Kc et al., 2018; Ogundari, 2017) found evidence for Bennett's Law in developing countries, especially in Nigeria and Bangladesh, where households consumed more vegetables, fruits, and meat as a result of increased purchasing power. In addition (Bailey, 2013), recorded evidence in Kenya of poor households using the additional income to diversify their food consumption before considering purchasing non-food items. Hence, we expect household income to have a positive impact on the NHDDI.

Household size impacts household dietary diversity in two different ways. On the one hand, it has a positive effect as it means more labor for agricultural work, for instance, the production of fruits and vegetables, improving dietary diversification (Workicho et al., 2016). On the other hand, it means a larger dependency ratio (Powell et al., 2017), implying budget constraints leading to buying more staples and forgoing expensive foods, like vegetables (Codjoe et al., 2016). The literature records ambiguous effects (Torheim et al., 2004). found a positive effect (Kc et al., 2018). (Powell et al., 2017) and (Rajendran et al., 2017) reported the opposite. As the negative effect dominates, we expect the same for Ghana.

The evidence for the relationship between the gender of the household head and NHDDI is mixed (Morseth et al., 2017). (Bukania et al., 2014) and (Rogers, 1996) showed that when women are responsible for food preparation, they have substantial control of the diet, leading to more protein-rich foods. However (Zakaria, 2017), found that women in Ghana have limited control over the household budget, except when they are household heads. Male household heads tend to significantly influence food consumption choices, especially among low-income households when food prices increase (Kassie et al., 2014). Furthermore, women in Ghana face more constraints in

holding property rights over land than men restricting their control over the household budget. For Ethiopia (Workicho et al., 2016), found that female-headed households have a higher probability of high dietary diversity than men-headed households. The reverse was found by (Powell et al., 2017) for Tanzania and by (Kaloi et al., 2005) for Uganda. Some studies also found an association between the gender of the household head and some specific foods, with men preferring more meat and carbohydrates and women more dairy products, sugar, and fruits (Berbesque & Marlowe, 2009). The food preferences may be related to the body's nutrient requirements (Berbesque & Marlowe, 2009). Males derive a significant portion of energy from carbohydrates and protein, whereas females more from fat (Bloomer & Fisher-Wellman, 2008). By the above, we expect the effect of the gender of the household head on the HDDI to be uncertain (Morseth et al., 2017).

Various studies discussing the effect of marital status on household dietary diversity (e.g Mekuria et al., 2017; Obayelu, 2012) noted that the combined knowledge of the wife and husband and the pooling of resources are likely to increase the likelihood of consuming more diversified foods Obayelu (2012) found that marital status is positively associated with dietary diversity in North-Central Nigeria. Similar findings were reported by (Cordero-Ahimán et al., 2017) for the indigenous Sierra Tarahumara communities in Mexico, where couples tend to supplement each other's efforts to provide food for the household (Nørgaard & Brunsø, 2011) found that partners encourage each other in healthy diet choices as they care about each other's nutrient intake. Based on the above arguments, we expect married couples to have a higher NHDDI.

Education has a positive impact on nutrition literacy and thus on dietary diversity. The more people are educated, the better their nutritional knowledge and ability to put such knowledge into practice (Ragasa et al., 2019). In Malawi (Kuchenbecker et al., 2017), found that education positively affects dietary diversity. Similar findings were reported by (Kc et al., 2018) for Cameroon and Ghana. Therefore, we posit that education positively influences food diversity (see (Kiboi et al., 2017)).

Another predictor of household dietary diversity is the number of children under five years in the household (Iqbal et al., 2017) found a negative association for Pakistan. Similar findings were reported by (Frempong & Annim, 2017) using data obtained from the Ghana Multiple Indicator Cluster Survey and by (Cisse-Egbuonye et al., 2017) for the Zinder and Maradi regions in Niger (Ciaian et al., 2018). also found a negative association among the Roma population in Romania. The rationale is that if the number of children under five increases, the burden of feeding them also increases (Frempong & Annim, 2017). Moreover, for poor households, the number of children under five shifts parents' time and resources from agricultural work to the caretaking of the children, notably nursing and clothing (Komatsu et al., 2018). Consequently, we hypothesize a negative impact on the NHDDI.

The last determinant is NAFCO which, as described in section 2, increases and stabilizes the returns on smallholder farmers' staples via stable prices of cereals, reduces risk, and saves travel time for selling the produce at the market. Hence, we expect a positive impact of NAFCO on the NHDDI.

In addition to the above determinants of the NHDDI, we consider three interactions: the number of children under five years X education, the number of children under five years X income, and household size X the number of children under five years. We expect the interaction effect income X the number of children under five years to reduce the negative main effect of children under five years (Alderman & Headey, 2017; Frempong & Annim, 2017). The effects of the other interaction effects are uncertain.

4. Materials and methods

4.1. Data and descriptive statistics

We obtained data from a survey conducted in 2015 for a study on Gender and Agriculture for the Ministry of Food and Agriculture (MoFA). The survey, was conducted by the Consultancy and Innovation Directorate of the Ghana Institute of Management and Public Administration. The

survey's main objective was to gather information on differences in rural households' agro-diversity practices to reduce the impacts of climate change on food production systems. The survey used multistage stratified random sampling by dividing the country into four agricultural zones: the Guinea Savanna, the Coastal Savanna, and two Transition and Forest zones. The agricultural zones were divided into NAFCO (policy-on) and non-NAFCO (policy-off) areas. The division yielded six clusters from which a total of 30 maize-growing communities were randomly selected (see Appendix 1 for details).

For each community, smallholder farmers were randomly selected from lists provided by the District Directorate of the MoFA. The number of farmers selected was proportional (approximately 5%) to the number of maize farmers in each community. The total sample consisted of 305 farming households: 126 in the policy-on areas and 179 in the policy-off areas. Face-to-face and pen-to-paper methods were used to collect the data. Before the field survey, the enumerators (CID staff) were trained. The questionnaire was pre-tested, and all ambiguities were clarified. The interviewee was the head of the household and persons responsible for preparing food.

The food group items consumed by the household used in the study are presented in Table 1. The reference period was one week, covering a complete standard diet cycle that is not too long for accurate recollection. Food consumed during special occasions, such as funerals and parties, was not included, nor foods consumed outside the home, such as food purchased on the street, as the NHDDI is designed to reflect dietary diversity among all household members. Table 2 presents the definition and measurement of each variable and the sign of its impact on the NHDDI, as described in section 2.

4.2. Estimation strategy

In this section, we first discuss coarsened exact matching and next estimation of the treatment effect by ordered probit regression.

4.2.1. Coarsened exact matching (CEM)

Participation in the NAFCO is non-random: it is based on a farmer's interest and willingness to participate, i.e., self-selection. Accordingly, several of the determinants of the NHDDI, such as education or marital status, can also be determinants of the decision to participate in the NAFCO, leading to confoundedness, and thus spurious correlation and biased estimation. We applied coarsened exact matching (CEM) to correct confoundedness. CEM matches the treated and control group on key characteristics by creating "statistical twins" for the counterfactual group (Firestone, 2015; S. M. Iacus et al., 2011). Matching on the confounding factors thus creates a credible counterfactual.

CEM is a non-parametric method of pre-processing the data to control confoundedness by reducing the imbalance between the treated and control groups (S. M. Iacus et al., 2011). It involves recoding a variable's scores so that substantively similar values are grouped and assigned the same numerical value (S. M. Iacus et al., 2011). It allows adjusting the imbalance on one variable without affecting the imbalance of another variable (Blackwell et al., 2009).

CEM leads to a set of strata of the original outcomes. The treated individuals are matched with those in the control group within each stratum. Unmatched individuals in the control group are discarded. The CEM approach coarsens covariates according to the researcher's information (researcher-defined) or automatically (Blackwell et al., 2009). It allows balancing between the treated and the control group ex-ante rather than ex-post-like propensity score matching (S. M. Iacus et al., 2011).

CEM often produces strata of different sizes. Weighting is applied to account for different numbers of treated and control units in a stratum. Let T^s denote the set of treated units in stratum

Table 2. Description of the variables

No	Variable	Definition	Measurement	Expected Sign
1	NHDDI	Nutrient-content HDDI	NHDDI levels: 1: low; 2: basic, 3: moderate, 4: adequate, and 5: high	
2	NAFCO	Participant in buffer stock operations	Dummy: NAFCO farmer=1, Non-NAFCO farmer =0	+
3	Chn	Number of children under five	Number of children under five years	–
4	Gen	Gender of the household head	Male =1, Female=0	±
5	Mar	Marital status of the household head	Married =1, uUnmarried=0	+
6	Edu	Education of the household head	No formal education=0; Formal education=1	+
7	HS	Household size	Number of people in the household	±
8	Inc	Household annual income	The amount in Ghana Cedis earned	+
9	ChnXEdu	Children<5 X Education		±
10	ChnXInc	Children<5 X Income		+
11	ChnXHS	Children<5 X Household size		±

s with $\text{count}_{T^s} = \# T^s$. Similarly, for the control units: $m_C^s = \# C^s$. In addition, $m_T = \bigcup_{s \in S} m_T^s$ and $m_C = \bigcup_{s \in S} m_C^s$ with s the total number of strata in a variable. To each matched unit i in stratum s , CEM assigns a weight (Nilsson et al., 2019; S. M. Iacus et al., 2011):

$$w_i = \begin{cases} 1, i \in T^s \\ \frac{m_C}{m_T} * \frac{m_T^s}{m_C^s}, i \in C^s \end{cases} \quad (1)$$

The unmatched units receive weight $w_i = 0$.

The matching success is measured by the univariate imbalance measure I_1 and the multivariate imbalance measure L_1 . The univariate imbalance measure is variable-specific. For variable j , it is defined as the difference between the averages of the treated and control group (Corneo et al., 2010):

$$I_1^j = \bar{X}_{m_T, w}^j - \bar{X}_{m_C, w}^j \quad j = 1, 2, \dots, k \quad (2)$$

which are calculated under the application of the weight w defined in (1) above.

The multivariate imbalance measure L_1 is a summary of the overall imbalance between the treated and the control strata. It is calculated by simultaneously comparing the differences between the matched covariates and their interactions (Firestone, 2015):

$$L_1(f, g) = \frac{1}{2} \sum_{\ell_1, \dots, \ell_k \in H(X)} |f_{\ell_1, \dots, \ell_k} - g_{\ell_1, \dots, \ell_k}| \quad (3)$$

where $f_{\ell_1, \dots, \ell_k}$ and $g_{\ell_1, \dots, \ell_k}$ are the relative frequencies for the treated and untreated units, respectively, and $H(X)$ is the set of values generated by coarsening with continuous variables recoded and binary and categorical variables retaining their original values (Dooley et al., 2014). Note that for pre-matching, $H(X)$ is just the set of the original values. The L_1 statistic ranges from 0 to 1, with higher values denoting more imbalance. To assess the matching quality, the pre-and post-matching imbalance measures are estimated and compared. A reduction in both I_1 and L_1 indicates an improved balance. While there is no generally accepted threshold for L_1 (Firestone, 2015), recommends 0.2 as an acceptable level.

4.2.2. Estimation of the treatment effect

Based on the user-defined or automatically defined coarsened data, the impacts of the determinants on the NHDDI are estimated by ordered probit regression. The probit model is of the form (Greene, 2018):

$$y^* = \beta X_i + \varepsilon_i, \quad i = 1, 2, \dots, n \quad (4)$$

where for respondent i y^* is a latent variable determining the NHDDI category, X_i the vector of explanatory variables; β the vector of coefficients, and ε_i the random error term following a standard normal distribution. The unobserved variable y^* is related to the observed NHDDI variable, as (Greene, 2018):

$$\begin{cases} y = 0 & \text{if } y^* \leq 0 \\ = 1 & \text{if } 0 < y^* \leq \mu_1 \\ = 2 & \text{if } \mu_1 < y^* \leq \mu_2 \\ \vdots \\ = J & \text{if } \mu_{J-1} < y^*, \end{cases} \quad (5)$$

where μ_1 to μ_{J-1} are the unknown threshold values for the NHDDI categories. The probabilities of the observed outcomes for the ordered probit model are estimated as (Piedra-Bonilla et al., 2020):

$$\begin{aligned} \text{Prob}(y = 0) &= \Phi(-\beta_i x_i) \\ \text{Prob}(y = 1) &= \Phi(\mu_1 - x' \beta) - \Phi(-x' \beta) \\ \text{Prob}(y = 2) &= \Phi(\mu_2 - x' \beta) - \Phi(\mu_1 - x' \beta) \\ &\vdots \\ \text{Prob}(y = J) &= 1 - \Phi(\mu_J - x' \beta) \end{aligned} \quad (6)$$

where Φ is the cumulative function of the standard normal distribution. The ordered probit model is interpreted through the marginal effects, which measure the change in probability given a one-unit change in the independent variable. The marginal effect is computed as (Piedra-Bonilla et al., 2020):

$$\frac{\partial P(y = j)}{\partial x} = \left[\Phi(\eta_j = \beta_i x_i) - \Phi(\mu_{i+1} - \beta_i x_i) \right] \quad j = 0, 1, \dots, 4 \quad (7)$$

The empirical model (5) is specified as:

$$\begin{aligned} \text{NHDDI}_i &= \beta_0 + \beta_1 \text{NAFCO}_i + \beta_2 \text{Chn}_i + \beta_3 \text{Mar}_i + \beta_4 \text{Edu}_i + \beta_5 \text{Gen}_i + \beta_6 \text{HS}_i + \beta_7 \text{Inc}_i + \beta_8 \text{Chn}_i \text{XEdu}_i + \\ &\beta_9 \text{ChnXInc}_i + \beta_{10} \text{ChnXHS}_i + \varepsilon_i \end{aligned} \quad (8)$$

with β_{1-10} the unknown parameters and ε_i the error term. The ordered probit model is estimated by maximum likelihood (ML) using STATA 14.

For comparison, we also estimated (5) by weighted least squares (WLS) where the weights are the CEM weights in equation (1).

5. Results and discussion

In presenting the results of the analysis, we first presents the descriptive statistics and followed by the results from the analysis of the data based on the matchings based on equations 1–3. Then, the results from the estimation of the casual effects based on the application of equations 5–9.

5.1. Descriptive statistics

Table 3 presents descriptive statistics for the treated and control group. The former consists of NAFCO participants in the policy-on areas (the policy-on areas contain both participants and non-participants) and the control group of farmers in the policy-off areas. Note that the subsample of NAFCO farmers entails the risk of self-selection. We resolve this issue by matching participants and non-participants using coarsened exact matching (see section 3.2).

Table 3 shows that the mean NHDDI level in the policy-off area is 1.87 and 3.90 in the policy-on area. The table furthermore shows substantial income differences between the policy-off and policy-on regions: 1900.00 Cedis versus 6730.00 Cedis, respectively. The average education level and proportion of households with married heads are higher in the policy-on areas than in the policy-off areas: 1.56 versus 1.34 and 92% versus 79%, respectively. The reverse holds for the average number of children under five, household size, and the proportion of male-headed households: 1.18 versus 1.90, 6.28 versus 6.41, and 75% versus 76%, respectively.

5.2. The CEM matching results

As a first step to the casual estimation of the effects/impacts, we conducted imbalance checks of the raw data using automatic and user-defined coarsening. We considered gender, marital status, education, and household size as possible confounding covariates as these variables were found to influence participation in the buffer stock operations initiative (Abokyi et al., 2020). For the dummy variables gender, marital status, and education, we considered two categories (bins). For household size ranging from 1–17, we considered three bins: small (1–4 members), medium (5–8 members), and large (9–17 members). The user-defined outcomes are presented in Table 4 (the automatically defined results in Appendix 2).

Table 3. Descriptive statistics

Variable	Policy-off				Policy-on			
	Mean	S. Dev.	Min.	Max.	Mean	S. Dev.	Min.	Max.
NHDDI	1.87	1.01	1.00	4.00	3.90	1.21	1.00	5.00
NAFCO	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
Chn	1.90	1.28	0.00	3.00	1.18	1.31	0.00	3.00
Mar	0.79	0.41	0.00	1.00	0.92	0.27	0.00	1.00
Edu	1.34	0.47	1.00	2.00	1.56	0.50	1.00	2.00
Gen	0.76	0.43	0.00	1.00	0.75	0.44	0.00	1.00
HSS	6.41	2.24	2.00	16.00	6.28	2.28	3.00	17.00
Inc (in 1000)	1.90	2.03	0.10	12.00	6.73	5.37	0.12	20.00
ChnXEdu	3.67	3.67	0.00	15.00	3.43	4.00	0.00	12.00
ChnXInc	2.80	3.51	0.00	20.70	8.74	6.86	0.00	19.00
ChnXHS	12.09	8.77	0.00	39.00	7.72	9.03	0.00	30.00
No. of obs.	179	-	-	-	126	-	-	-

Table 4 presents the imbalance measures for the raw data (panel A) and the CEM data (panel B). Comparing the panels A and B shows that matching reduced I_1 to virtually zero for Gen, Mar and Edu and to less than 0.1 for HH and that L_1 decreased from 0.395 for the raw data to 0.128 for the CEM data which is smaller than the threshold of 0.2 recommended by (Firestone, 2015). Appendix 2 shows that the automated coarsening results align with the user-defined results in Table 5. Overall, the results indicate that CEM has substantially reduced the heterogeneity between the policy-on and the policy-off groups.

5.3. The ordered probit and WLS results

Table 5 presents the ordered probit and WLS estimates based on the user-defined coarsened data. The results based on automated coarsened data are presented in Appendix 3. The results in Table 5 show that the ordered probit estimates align with WLS results. Notably, the coefficients have the same signs supporting the robustness of the estimates. The goodness of fit statistics for the ordered probit analysis is quite acceptable, especially in the light of a cross-section study. Finally, the significant ordered probit estimates of the thresholds indicate that the variables were ordered correctly.

The main results are as follows. The estimated coefficient of *NAFCO*, reported in Table 5, for Weighted Ordered Probit estimates and the WLS estimates are positive and significant at 1% indicating that *NAFCO* has had a positive impact on the food security measured by NHDDI.

As expected, the estimated coefficient of *NAFCO* is negative for *low* and *basic* and positive for the other categories, especially for *adequate*. The marginal effects improve from *basic* (−20%) to an *adequate* category (38%). The improvement in the marginal effects of *NAFCO* imply that participation in the buffer stock initiative improves one's NHDDI. These signs indicate that households are pushed away from the lower categories towards the higher levels. It follows that participation in the buffer stock initiative improves a household's NHDDI. This results mean that *NAFCO* help to improve the utilization dimension of food security.

The marginal effects of income are also significant for all the higher NHDDI levels (moderate—high). These imply that income has a positive impact household food security. Also, the marginal effects of income show that an increase in income increases the likelihood of pushing people from low and basic adequacy levels to higher NHDDI levels. The negative marginal effects of income, for *basic* and *low*, indicate that households are less likely to be in the low and basic NHDDI by 13% and 19%, respectively, when income increases. The results mean that income has a significant negative impact on low and basic and a significant positive effect on the other categories confirming Bennett's law. The result is also in line with the findings of (Kc et al., 2018; Rajendran et al., 2017) and (Jones et al., 2014) who recorded a positive, significant effect of income on food security. Note that the positive impacts of income on the higher NHDDI levels are smaller than those of *NAFCO*, indicating that the combined *NAFCO* effect of stable prices, reduced risk, and saved travel time is larger than the income effect.

The number of children under five years has significant positive effects on low and basic and negative effects on the other categories, indicating a depressing effect on the NHDDI. These results are consistent with the findings of (Cisse-Egbuonye et al., 2017; Frempong & Annim, 2017) and (Iqbal et al., 2017). However, the depressing effect is mitigated by the interaction terms of the number of children under five years with income and education, respectively.

The number of children under five years (*Chn*), has a significant negative effect on NCHDDI. The marginal effects further indicate that with an increase in *Chn*, there is a likelihood of households moving to a lower NCHDDI level. For instance, the marginal effects suggest that there is 8.9% and 11.8% likelihood, that an increase in the number of children under five will move households into the *basic* and *low* NCHDDI, respectively. Furthermore, the results in Table 6 shows a negative 51% for high NCHDDI as the number of children under five years increases. These outcomes support the hypothesis that having children less than five years divert parents, especially mothers' time and

Table 4. Imbalance checks of the raw (A) and coarsened data (B)

A: Raw data									
Variable	Mean of the control group	Mean of the treated group	Difference in means (I_1)	Between-group difference in means per quantile					
				min	25%	50%	75%	max	
Gen	0.76	0.75	-0.014	0	-1	0	0	0	0
Mar	0.79	0.92	0.133	0	0	0	0	0	0
Edu	1.34	1.56	0.220	0	0	1	0	0	0
HH	6.41	6.28	-0.130	0	0	0	0	-3	
Multivariate imbalance measure L_1									
			0.395	-	-	-	-	-	-
B: After coarsening									
Variable	Difference in means (I_1)			Between-group difference in means per quantile					
				min	25%	50%	75%	max	
Gen	-5.60E-16			0	0	0	0	0	0
Mar	-1.10E-16			0	0	0	0	0	0
Edu	-2.20E-16			0	0	0	0	0	0
HH	-0.068			0	0	0	0	-3	
Multivariate imbalance measure L_1 0.128									
				-	-	-	-	-	-
Observations				Policy -off			Policy-on		
All				179			126		
Matched				160			120		
Unmatched				19			6		

resources from farm work and thus reduces NCHDDI. The results are consistent with the findings of other studies (Cisse-Egbuonye et al., 2017; Frempong & Annim, 2017; Iqbal et al., 2017).

Education, gender, and marital status have significant negative impacts on low and basic and significant positive effects for the other categories. The results for education as expected, implies that more educated people tend to have better NHDDI than the less educated as education is likely to improve the nutrient content of the food choices of households make. The result is consistent with the theory that education is associated with increased nutrition knowledge, and an indicator of the ability of individual to translate nutrition knowledge into better dietary practices (Hiza et al 2013). The results for education are in line with (Kiboi et al., 2017; Powell et al., 2017) and (Ochieng et al., 2017) who showed that education is associated with increased nutrition knowledge. The results also corroborate the findings Malapit et al. (2015) that households with their heads well educated are more likely to be food and nutrient secured than those with less educated heads.

A possible explanation for the gender effect is that the double responsibility of women as mothers and household heads, including principal farmers, induces them to opt for the upper levels of food security. A possible reason that could account for this is that when women farmers double as mothers, it affects their production volumes and the diversity of the crops they cultivate, leading to low dietary diversity (Hitomi et al., 2018; Ochieng et al., 2017). The results are consistent with the findings of (Ochieng et al., 2017) in their study of dietary diversity among agriculture-dependent households in Tanzania, and the study by Nithya and Bhavani (2018) in rural India. who reported that male-headed households have better dietary diversity than female-headed ones.

The sign of marital status supports the hypothesis that the combined knowledge of couples living together and pooling resources leads to higher levels of the NHDDI (Obayelu, 2012). The finding further lends support to the noting that married couples enjoy more nutrient adequate diets compared to their unmarried counterparts. Similarly, their probability of moving from moderate to adequate is 37%, and from adequate to high is 11.3%, when the head of the household marries. As marriage also involves a combination of two significant incomes, married people can afford more expensive nutritious and diverse foods and hence improved food security.

The negative and significant sign of household size for the upper levels of NHDDI indicates that large households experience problems meeting the increased demand for food and are more likely to prioritize their carbohydrate needs. Similar results were obtained by (Bukania et al., 2014) and (Ochieng et al., 2017). Thus, we find a negative and significant association between household size (HS) and NHDDI, indicating that increasing the former hurts nutrient content of the household's food intake. The marginal effects suggest that as household size increases, the likelihood of being in the low and basic NHDDI increases by 1.6% and 2.1%, respectively. We further find that increased household size pushes households out of the high, adequate, and moderate NHDDI, with probabilities of 0.9%, 3.0%, and 0.2%, respectively. The results suggest that as household size increases, households that are unable to meet the increased demand for food are more likely to prioritize their carbohydrate needs resulting in a deficiency of some vital nutrients (Bukania et al., 2014). These findings corroborate those of (Ochieng et al., 2017) about the negative association of household size and dietary diversity in Tanzania and the study by Koppmair et al. (2017) in Malawi.

The negative sign of the interaction term with of income with the number of children under five years is of particular concern. The interaction term, ChnXInc, has a positive effect on NCHDDI, with a coefficient of 0.093 at 1% statistical significance. This outcome of the results confirms the hypothesis that income mitigates the negative effect of children under five years in terms of nutrient security. Having more children restrict farmers' ability to enjoy a variety of food due to production challenges. With improved income, this effect is mitigated by the purchase of diverse food. The marginal effects show that the effect is greatest on moving from moderate to adequate nutrient adequacy level with a probability of 2.7%. The marginal effects further reveal that the interaction term reduces the likelihood of being in the basic and low nutrient adequacy levels by

Table 5. Ordered probit and WLS estimates of the Nutrient-Content Household Diversity Index (NCHDDI) based on user-defined coarsened data

Variable	Weighted Ordered Probit estimates						WLS estimates
	Regression coefficient	Marginal effects					
		Low	Basic	Moderate	Adequate	High	
NAFCO	1.332*** (0.198)	−0.205*** (0.037)	−0.271*** (0.049)	0.029*** (0.009)	0.388*** (0.067)	0.118*** (0.038)	1.160*** (0.134)
Income	0.093*** (0.023)	−0.014*** (0.004)	−0.019*** (0.005)	0.002*** (0.001)	0.027*** (0.007)	0.008*** (0.003)	0.060*** (0.016)
Chn	−0.579*** (0.166)	0.089*** (0.027)	0.118*** (0.0037)	−0.012*** (0.005)	−0.168*** (0.052)	−0.051*** (0.018)	−0.431*** (0.130)
Edu	0.321** (0.162)	−0.049* (0.026)	−0.065* (0.034)	0.007* (0.004)	0.093* (0.048)	0.028* (0.015)	0.315** (0.127)
Gen	0.419** (0.166)	−0.064** (0.027)	−0.085** (0.035)	0.009** (0.004)	0.122** (0.050)	0.037** (0.017)	0.263** (0.133)
Mar	1.284*** (0.294)	−0.198*** (0.052)	−0.261*** (0.068)	0.028*** (0.010)	0.374*** (0.094)	0.113*** (0.035)	0.958*** (0.212)
HS	−0.103*** (0.040)	0.016** (0.006)	0.021** (0.009)	−0.002** (0.001)	−0.030** (0.012)	−0.009** (0.004)	−0.090*** (0.031)
ChnXInc	0.093*** (0.024)	−0.014*** (0.004)	−0.019*** (0.006)	0.002*** (0.001)	0.027*** (0.0)	0.008*** (0.003)	0.075*** (0.018)
ChnXEdu	0.039*** (0.014)	−0.006*** (0.002)	−0.008*** (0.003)	0.001** (0.000)	0.011*** (0.004)	0.003*** (0.001)	0.029*** (0.011)
ChnXHS	0.027 (0.023)	−0.004 (0.004)	−0.005 (0.005)	0.001 (0.001)	0.008 (0.007)	0.002 (0.002)	0.022 (0.018)
Constant	−	−	−	−	−	−	1.151*** (0.408)
Threshold parameters							
μ ₁	0.894* (0.536),						
μ ₂	1.805*** (0.542)						
μ ₃	2.592*** (0.552),						
μ ₄	4.011*** (0.576)						
Log-likelihood	−315.47					F	43.70***
Wald Chi X ²	265.06***					R ²	0.616
Pseudo R ²	0.300					Adj R ²	0.601
	−					RMSE	0.901
Obs.	280					Obs.	280

Note. ***, **, *: significant at the 0.01, 0.05, and 0.1 level, respectively. Standard errors are in parentheses.

1.9% and 1.4%, respectively. The results are consistent with the findings of (Frempong & Annim, 2017) and Malapit et al. (2015) that improve income helps to reduce the negative effect of children on households' food consumption, nutrient and dietary diversity. Similarly, we find the interaction term, ChnXEdu, to be positively associated with NCHDDI at 5%, suggesting that education mitigates the negative effect of having more children less than five years. The result confirms the suggestion that the nutrients intake of children during their early years depends mainly on the behavior and decisions of the parents based on their knowledge (Jones et al., 2014). Therefore, for educated people with the view of making healthy food choices for their children, this interaction effect of education and number of children under five years can mitigate the negative effect of the later.

The results demonstrates that using public buffer stocks as a tool to improve income and food security (ie access and utilization) by smallholder using the buffer stock policy can be successful. The results mean that, if the current public buffer stockholding policy operations are extended to other crops (cereals) and maize growing areas of the country, the initiative is likely to impact positively on smallholder farmers' food security. However, a more concerted effort to improve access to efficient markets to improve and stabilize farmers' incomes is critical. Ghana could evaluate continuously the price level in the light of the trade-off between farmers' reasonable income and structural transformation across time and space.

The results imply that without sustained income, farmers' only alternative to sustain their nutrient-content dietary diversity is for farmers to rely on their own productions for the consumption of diversified diets. Smallholder farmers need to diversify their crop production to broadening production to include vegetables and livestock, if the gains in nutrient-content dietary diversity following from the participation in the buffer stock operations are to be sustained. If the relevance of nutrition is to be integrated into food security measurement, then surely an indicator that captures both the macro and micro-nutrients and their densities such as the NHDDI is required. The nutritional relevance capture by the NHDDI can be maximized for measuring food and nutritional security. The novel NHDDI is a promising tool for measuring food and nutrition security

6. Conclusion and policy implications

Food security has become a fundamental human right, as stated in the United Nations Universal Declaration of Human Rights (Article 25), and a development goal. This paper derives its motivation from the Declaration and the development goal and examines food security among smallholder farmers in Ghana participating in the National Buffer Stock Programme (NAFCO). Despite increased food production, malnutrition is still prevalent in rural Ghana. The malnourished households typically face monotonous diets of starchy staples such as rice, maize, and tubers. The lack of dietary diversity causes severe problems, including physical and brain stunting and death.

NAFCO is a hedging policy against income losses and uncertainty due to price fluctuations from farming activities, primarily the production of cereals. It works by purchasing produce at a fixed price set by the government above the open market prices during the glut period. To measure the impact of NAFCO on food security, we introduced the nutrient-content household dietary diversity index (NHDDI), which is a re-classification of the household dietary diversity index (HDDI), to reflect the adequacy of the diet. The NHDDI considers the nutrient content adequacy of each food item by stratifying the HDDI items into five categories: low, basic, moderate, adequate, and high.

The data analyzed are cross-sectional data from 305 maize farmers, 126 NAFCO participants, and 179 non-participants. The data measure, among other things, the food items consumed by a household over a one-week reference period. Coarsened Exact Matching (CEM) was applied to control for selection bias and confoundedness. The coarsened data was analyzed using Weighted Least Squares and weighted ordered probit analyses to estimate the impact of NAFCO, controlling for a set of controls derived from the literature

The findings indicate that participation in the NAFCO and income positively affect food security. In addition, marital status, gender, and education were found to have positive effects, whereas household size and children younger than five years showed negative impacts. The latter effect, however, is mitigated by income and education. The study's primary outcome is that NAFCO contributes positively to participating smallholder farmers' food security. As NAFCO intervention reduces supply during the glut, we concluded that it also has a positive price effect for non-participants. To what extent this leads to improved food security for non-participants needs further investigation. The impacts on consumers are even more uncertain. There is a negative welfare effect due to an upward price effect because NAFCO takes large volumes out of the open market during the glut season, thus reducing the open market volume. The extent of the negative welfare effect depends on the reduction of the open market volume. Note that this negative welfare effect

could be reduced if the volumes taken out of the open market by NAFCO were released to the open market when prices are high, as in the case of standard buffer stock intervention with two interventions (buying during the glut, release when supply is tight). Depending on the volumes and the price level, this could lead to welfare improvement. There could also be a positive welfare effect for consumers if NACO leads to an improvement of the quality and quantity of agricultural output due to the upward price effect and welfare improvement of smallholder farmers. Finally, large institutional buyers have a positive welfare effect, such as high schools to which the buffer stocks are sold. In conclusion, NAFCO in its present form has positive effects on food security for participants, positive but smaller, price effects for non-participating smallholder farmers, and negative effects for consumers at large. The latter effect could be reduced by implementing a buffer stock policy consisting of buying during the glut and selling when supply is tight.

For NAFCO to continue to improve the food security situation of farmers, there is the need to review the current NAFCO program and incorporate food and nutrition literacy education aspects into the design of NAFCO. Incorporating nutrition education into the current design or establishing nutrition education programs into the food systems might proactively promote healthy food choices and eating among rural farmers who seem to be eating monotonous diets in spite of improvement in their incomes. This could be promoted through the extension agents that provide marketing information about NAFCO to farmers.

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Notes

1. NAFCO affects the open market price of cereals depending on the volumes of NAFCO interventions. Benin et al. (2013) estimated the volume of the NAFCO to be 5% in 2012, while MoFA (2017,) estimated it to be about 10% in 2016 and approximately 15% in 2020, respectively. The intervention volumes and the price differential between the open market price and the NAFCO price spillover to open market prices, leading to, for instance, higher prices for non-participants and consumers. However, for the present analysis which focuses on food security for NAFCO participants, this issue is not relevant as the price the participant receives is pre-determined by NAFCO (see section 3.2 for details).
2. In the 2011/2012 farming season, for instance, the NAFCO price was fixed such that a participant

obtained at least a 27% profit margin compared to the glut period price (Benin et al., 2013).

Disclosure statement

The authors report no conflict of interest

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Appendix 1: Survey Communities

Ecological Zone	Policy-on/off	District	Communities
Guinea Savannah	Policy-off	Wa	Piisi and Tanvaari
		Tumu	Sakai and Wellembele
		Jirapa	Baazu and Degri
	Policy-on	Damongo	Alhassan Kuraa and Attributo
		Nanton	Kanshegu and Mogla
		Bimbila	Afayili and Taali
Transitional zone	Policy-on	Bechem,	Ohia Animguasie and Terchire
		Wenchi	Ahyiaem and Wurompo
		Atebubu	Old Kokrompe and Ohia Animguasie
	Policy-off	Nkwanta	Kpala and Krumase
Rain Forest	Policy-off	Axim,	Wassa Agona and Wassa Simpa
		Juabeso,	Juaboso and Afia
		Tarkwa Nsuaem,	Wassa Agona and Wassa Simpa
		Kpando	Kpando Gadza and Sovie-Kudzra
Coastal Savanna	Policy-off	Keta	Bawe and Dekugbor

Appendix 2: Matching results for automated coarsening

A: Raw data									
Variable	Mean of the control group	Mean of the treated group	Difference in means (I_1)	Between-group difference in means per quantile					
				min	25%	50%	75%	max	
Gen	0.76	0.75	-0.014	0	-1	0	0	0	0
Mar	0.79	0.92	0.133	0	0	0	0	0	0
Edu	1.34	1.56	0.220	0	0	1	0	0	0
HH	6.41	6.28	-0.130	0	0	0	0	-3	
Multivariate imbalance measure L_1				-	-	-	-	-	-
After automated coarsening:									
Variable	Difference in means (I_1)		Between-group difference in means per quantile						
			Min	25%	50%	75%	Max		
Gen	-4.40E-16		0	0	0	0	0	0	0
Mar	-1.10E-16		0	0	0	0	0	0	0
Edu	-8.90E-16		0	0	0	0	0	0	0
HH	-0.029		0	0	0	0	0	0	0
Multivariate imbalance measure L_1		0.168							
			Policy-off			Policy-on			
All			179			126			
Match			155			109			
Unmatched			24			17			