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Chemical Pesticides Adoption and Rural Welfare in Cameroon: An Empirical Analysis of Intensity and Timing Effects Using Endogenous Switching Regression and Multinomial Treatment Models

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Abstract

This article conducts an inclusive assessment of the effect of chemical pesticides adoption on rural household welfare in Cameroon. From a multidimensional perspective within the background of the Sen's capability approach, the study uses cross-sectional rural household-level data collected in 2024 from a randomly selected sample of 920 rural households from 2 of 5 agro-ecological zones in Cameroon. We estimate the causal impact of chemical pesticide adoption by applying endogenous switching regression and multinomial treatment effects models to assess results robustness. This helps us estimate the welfare effect of chemical pesticides adoption by minimizing the bias from the selection problem on pesticides adoption decisions. The results show that the average treatment effect on household welfare with and without adopting chemical pesticides is respectively 0.705 and 0.587. Therefore, adopting chemical pesticides for crop protection helps to improve the welfare level of rural households despite some effects on human health. Compared with households that do not adopt pesticides, the welfare level of households adopting a high or low degree of chemical pesticides increases by 20% and 15%, respectively, and the welfare level of households given the early or late adoption of pesticides increases by 7.30% and 5.9%, respectively. This confirms that chemical pesticides directly improve rural household welfare by significantly raising agricultural income and reducing monetary poverty and food insecurity, though these gains necessitate careful consideration of associated health and environmental costs.

Keywords

Chemical Pesticides, Household Welfare, Endogenous Switching Regression Model, Multinomial Treatment Effects Model

1. Introduction

Over the last decade, agriculture has emerged as a key pillar of structural transformation of economies, offering considerable potential for development in numerous countries in sub-Saharan Africa (SSA), including Cameroon. Several authors in the literature agree that to date, the agriculture sector in SSA still has a significant impact on economic growth, employment, and food safety[1] [1]-[3]. However, its impact on reducing poverty in rural areas remains limited, with more than 60% of the rural population in 17 countries still affected by this scourge [4]. Furthermore, despite significant progress, agricultural productivity in SSA has remained relatively low compared to other regions such as Europe, Asia, or Central America [5]. In Cameroon particularly, the low productivity and poverty of rural households have been intensified by the conjunction of some agronomic and socioeconomic constraints, including the effects of climate change, pest invasions, high post-harvest losses, low income of producers, limited access to agricultural technologies, and other inputs such as improved seeds, fertilizers, or chemical pesticides. Since the 80s, the objective of increased agricultural productivity in Cameroon by supplying additional inputs like chemical pesticides has then been one of the orientations of agricultural policy [6] [7]. According to the National Institute of Statistics [8] and [9], over 70% of Cameroonian small scale farmers use chemical pesticides for crop protection. Those pesticides are generally sprayed to treat crops with high economic returns, where production losses can be estimated at 80% - 100% of harvests [10] [11]. They are also adopted to treat traditional and cereal crops where the invasion of agricultural pests can affect 90% of production [12]. These productivity losses seriously impact the agricultural income of small scale farmers, which generally contributes to their welfare conditions. Several contemporary studies such as [13]-[15] establish an empirical relation between chemical pesticides use and the welfare of rural households. They demonstrate that the adoption of pesticides, in addition to ensuring plant health, increases agricultural yields and income. In the literature, [16] early formulated a set of assumptions stating that increased agricultural productivity and income by adopting agricultural inputs such as chemical pesticides leads to better yields, lower food prices, and improved welfare of rural households. However, increasing pesticides spraying can cause serious negative effects on human health and disproportionately lead to higher incomes. Indeed, in certain cases, the marginal benefit of pesticides

[1]The importance of agriculture is also demonstrated by its contribution to household food security in urban areas, where many households consume diversified agricultural products for their diet on a daily basis (Fages & Bricas, 2017).

use decreases while the costs of production on the farm continue to accumulate, which in the short term can unbalance the level of household income and therefore affect their welfare. In Cameroon, assessment of the impact of chemical pesticides use on household welfare seems very embryonic due to a lack of appropriate data, and most of previous research did not move beyond estimating the economic surplus and return on investment of pesticides adoption. In light of these observations, the main contribution of this article is to improve the literature on the issue of chemical pesticides use in Cameroon from a rural household welfare perspective. It allows us to investigate the role that chemical pesticides adoption can play in improving welfare specifically in rural areas of Cameroon. To better understand the impact of chemical pesticides on welfare, this study relies on a theoretical framework and a review of empirical literature to lay its results within the broader scientific context.

2. Theory and Literature Review Underpinning the Study

Although an empirical assessment of the contribution of pesticides use to poverty reduction in rural areas has not received any particular attention from researchers in Cameroon, a theoretical framework can be established based on the concept of household welfare. According to [17] and [18], the notion of welfare refers to the general theory of economic policy whose foundations were laid in the 20th century by [19] [20]. Welfare is part of neoclassical theory that studies the different states of the economy in terms of satisfaction achieved by individuals [21]. In line with its development, [22] considers three main phases of its applications. The first phase is found within the framework of the old economics of welfare, based on the works of [23]. It distinguishes between general welfare and economic welfare. Economic welfare can be measured by some indicators like income and/or consumption expenditures per adult equivalent [24]. The second phase is part of the new welfare economics represented by [25]-[27] and [20]. It is based on the concept of the Pareto optimum and assumes that some economic fluctuations will produce winners and losers of social assistance. Therefore, compensating the welfare of the losers produces economic variations that can stimulate growth and improve welfare. The third stage is modern welfare economics, represented by [28]. Sen's approach is based on the concepts of capabilities and functioning. He considers that gross domestic product per capita (GDP) is very limited as a criterion for assessing welfare. Indeed, he extends the concept of welfare and considers that it includes not only economic welfare but also non-economic welfare [23]. From an empirical point of view, these three stages in the theoretical analysis are related to three different forms of welfare assessment. Firstly, [6] [29] [30] and [31] measure the welfare of rural households through the prism of the old paradigm using economic indicators such as real income and household consumption expenditures. [32] adopt the concept of the new economics of welfare by measuring it through consumer and producer surpluses. Finally, [33] are founded on [34] theory of the capability approach, to build a system of indicators including the household's living situation, health, social status, psychological condition, and the household's economic condition to measure welfare. Recent developments in the literature have thus contributed to the evolution of welfare theory towards a multidimensional perspective. However, most of the research focuses on the effects on economic welfare, particularly on the adoption of agricultural technologies [35]. This research considers Sen's capability approach as the basic theoretical background. Taking income level and health status as the main outcome variables, it builds a rural household welfare index system. On this basis, rural households' welfare level is determined through fuzzy comprehensive assessment technique. In the literature, there are no existing studies in Cameroon that address the issue of the effect of pesticides use on rural welfare. Since productivity constraints and poverty are omnipresent in Cameroonian rural households' context, a comprehensive impact assessment of chemical pesticides use on rural household welfare will then contribute to the existing literature and provide new perspectives in terms of research on this issue.

3. Research Methods

3.1. Endogenous Switching Regression Model (ESRM)

The average effect of treatment on the welfare of Cameroonian rural households that use pesticides (ATT) and the average effect of treatment on the welfare of rural households that do not use pesticides (ATU) must be estimated in order to assess the impact of chemical pesticides use on poverty reduction for rural households. In the current literature on impact analysis, the propensity score matching (PSM) technique is used in the majority of studies [36] [37]. However, one of the limitations of the PSM method is that it can only minimize biases linked to observable characteristics. According to [38], it is possible to only control the differences in observed variables. However, there may be a bias resulting from unobserved variables that could affect the results whether or not individuals are treated. The ESRM is then used as an empirical method to avoid selection bias in our sample. Technically, two main steps characterize the ESRM. Firstly, we adopt a Probit model to identify the socioeconomic and agronomic characteristics that influence Cameroonian farmers to use chemical pesticides. The Probit model is specified as follows:

$$P_i^* = \beta X_i + \varepsilon_i \quad \text{with} \quad P_i^* = \begin{cases} 1 & \text{if } P_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

P_i represent the observed value of chemical pesticides adoption behavior for a Cameroonian rural household i. $P = 1$ means a rural household adopts chemical pesticides for crop protection, and $P = 0$ means the household does not adopt pesticides for plant protection and is therefore involved in organic farming. X_i indicates the sociodemographic, economic, and agronomic factors that influence rural household adoption behavior. β is the estimated coefficient of X_i, and ε_i is a random error term. In the second stage, we build an outcome equation to identify the main variables influencing a rural household's welfare level. Its specific form is as follows:

$$\begin{aligned} W_{i_0} &= \lambda_0 X_{i_0} + \varepsilon_{i_0} \text{ if } P = 0 \\ W_{i_1} &= \lambda_1 X_{i_1} + \varepsilon_{i_1} \text{ if } P = 1 \end{aligned} \tag{2}$$

With W_{i_1} and W_{i_0} defined respectively as the welfare levels of rural households that adopt and that do not adopt chemical pesticides for crop protection. λ_0 and λ_1 are regression coefficients, and finally ε_0 and ε_1 are the random error terms. The welfare level of Cameroonian rural households i depends on Equation (1). By performing a simple ordinary least squares estimation on Equation (2), there is a strong probability that the estimation results will be tainted by selection bias of the individuals due to the presence of observable and unobservable characteristics. Thus, this study considers all possible influences on the welfare of Cameroonian rural households by minimizing the sample selection bias due to both observable and unobservable characteristics. In addition, by building a covariance matrix Δ of the error terms, this paper addresses the issue of selection bias caused by unobservable factors, *i.e.*:

$$\Delta = \begin{bmatrix} \sigma_{\varepsilon 3}^2 & & & \sigma_{\varepsilon 3 \mu} \\ & \sigma_{\varepsilon 2}^2 & & \sigma_{\varepsilon 2 \mu} \\ & & \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1 \mu} \\ & & & \sigma_{\mu}^2 \end{bmatrix} \tag{3}$$

With σ_{μ}^2 the variance of the error term, $\sigma_{\varepsilon 1}^2$, $\sigma_{\varepsilon 2}^2$, and $\sigma_{\varepsilon 3}^2$ the variances of the error terms in the welfare functions, $\sigma_{\varepsilon 1 \mu}$, $\sigma_{\varepsilon 2 \mu}$, and $\sigma_{\varepsilon 3 \mu}$ the covariance of the error terms μ_i, ε_{1i}, ε_{2i}, ε_{3i}. Given the random disturbance term μ_i of the decision to adopt or not to adopt chemical pesticides and the random error terms ε_{i_1} and ε_{i_0} of the outcome equation are correlated with each other, the conditional expectations of ε_{i_1} and ε_{i_0} can be written as:

$$E\left(\varepsilon_{i_1} / P = 1\right) = \sigma_{u_1} \frac{\phi\left(X_i \beta\right)}{\Phi\left(X_i \beta\right)} = \sigma_{\mu_1} \lambda_{i_1} \tag{4a}$$

$$E\left(\varepsilon_{i_0} / P = 0\right) = -\sigma_{u_0} \frac{\phi\left(X_i \beta\right)}{1 - \Phi\left(X_i \beta\right)} = \sigma_{\mu_0} \lambda_{i_0} \tag{4b}$$

where ϕ and Φ are, respectively, the standard normal probability density function and the cumulative distribution function, $\lambda_{i_1} = \frac{\phi\left(X_i \beta\right)}{\Phi\left(X_i \beta\right)}$ $\lambda_{i_0} = \frac{\phi\left(X_i \beta\right)}{1 - \Phi\left(X_i \beta\right)}$ refers to Mills' inverse ratios reflecting rural households that have adopted chemical pesticides and those that have not adopted, which can be used to minimize the selection bias due to unobservable characteristics. In formula 2, we include error terms ε_{i_1} and ε_{i_0}; after we adjust the result equation, we obtain:

$$\begin{aligned} W_{i_0} &= \lambda_{i0} X_{i_0} + \sigma_{\mu_0} \lambda_{i_0} + \varepsilon_{i_0} \text{ if } P = 0 \\ W_{i_1} &= \lambda_{i1} X_{i_1} + \sigma_{\mu_1} \lambda_{i_1} + \varepsilon_{i_1} \text{ if } P = 1 \end{aligned} \tag{5}$$

In Equation (5) below, $\sigma_{\mu_0} \lambda_{i_0}$ and $\sigma_{\mu_1} \lambda_{i_1}$ are expressed as sample selection deviation correction terms. According to [38], the presence of unobservable characteristics contributes to sample selection bias, as shown when the covariance correlation coefficients $\rho_0\left(\frac{\sigma_{\mu_0}}{\sigma_\mu \sigma_0}\right)$ and $\rho_1\left(\frac{\sigma_{\mu_1}}{\sigma_\mu \sigma_1}\right)$ between the random error terms in the choice equation and the outcome equation are notably nonzero. Therefore, under the framework of the endogenous switching regression model, the rural household's welfare treatment effect will be specified as:

$$E\left(W_{i_1} / P=1; X\right)=\lambda_1 X_{i_1}+\sigma_{\mu_1} \lambda_{i_1} \tag{6a}$$

$$E\left(W_{i_{10}} / P=0; X\right)=\lambda_0 X_{i_0}+\sigma_{\mu_0} \lambda_{i_0} \tag{6b}$$

$$E\left(W_{i_{10}} / P=1; X\right)=\lambda_0 X_{i_1}+\sigma_{\mu_1} \lambda_{i_1} \tag{6c}$$

$$E\left(W_{i_1} / P=0; X\right)=\lambda_0 X_{i_0}+\sigma_{\mu_0} \lambda_{i_0} \tag{6d}$$

With (6a) and (6b) corresponding respectively to the welfare treatment effects of Camerounian rural households that adopted chemical pesticides and those that did not adopt. The formula (6c) denotes the supposed welfare treatment effect of rural households that adopted chemical pesticides if they had not adopted, and finally, (6d) is the hypothetical welfare treatment effect of rural households that did not adopt chemical pesticides if they had adopted. Since (6c) and (6d) are unobservable and unpredictable in the actual scenario, they are defined as counterfactuals. Therefore, the welfare average treatment effect of rural households that adopted chemical pesticides is the difference between (6a) and (6c), and the welfare average treatment effect of rural households that did not adopt chemical pesticides is the difference between (6d) and (6b).

$$\begin{aligned}
\mathrm{ATT} &= (6\mathrm{a})-(6\mathrm{c}) \\
&= E\left(W_{i_1} / P=1; X\right)-E\left(W_{i_{10}} / P=1; X\right) \\
&= \lambda_1 X_{i_1}+\sigma_{\mu_1} \lambda_{i_1}-\lambda_0 X_{i_1}+\sigma_{\mu_1} \lambda_{i_1} \\
\mathrm{ATU} &= (6\mathrm{d})-(6\mathrm{b}) \\
&= E\left(W_{i_1} / P=0; X\right)-E\left(W_{i_{10}} / P=0; X\right) \\
&= \lambda_0 X_{i_0}+\sigma_{\mu_0} \lambda_{i_0}-\lambda_0 X_{i_0}+\sigma_{\mu_0} \lambda_{i_0}
\end{aligned} \tag{7}$$

3.2. The Multinomial Treatment Effects model (MTEM)

Using the methodological approach of [23], this study categorizes Cameroonian households into two groups: those adopting chemical pesticides to a high degree and compares them with rural households that did not adopt pesticides, in order to validate the difference in welfare caused by pesticides adoption. A high degree of pesticides adoption and non-adoption of pesticides are the two sets of choice variables, which lead to inherent endogeneity constraints. Thus, in order to minimize sample selection bias and assess the effect of multivariate endogenous treatment variables on outcome variables, this paper also emphasizes the multinomial treatment effects model used by [39]. In fact, this model incorporates both decision and result equations. The first is used to estimate the probability that a Cameroonian rural household i will select the adoption level (m), such as:

$$P_r\left(P_{v_i} / X_i; l_i\right) = \frac{\exp\left(X_i'\alpha_m + l_{im}\right)}{1 + \sum_{k=1}^{M} X_i'\alpha_k + l_{ik}} \tag{8}$$

The result equation is used to assess how the different degrees of adoption affect the welfare of rural households that adopt pesticides in comparison with households that did not adopt. Specifically, it is given by:

$$E\left(W_i / P_{v_I}; Z_i; l_i\right) = \lambda_i X_i + \sum_{m=1}^{M} \delta_m P_{v_{im}} + \sum_{m=1}^{M} \lambda_m l_{im} \tag{9}$$

In formula (9), P_{v_i} denotes the observed value of the adoption degree of chemical pesticides of rural household i. $P_{v_i} = 1$ indicates the adoption degree (high or low), and $P_{v_i} = 0$ indicates that the rural household did not adopt pesticides. $m = 0, 1, 2$, indicate non-adoption, a high degree of adoption, and a low degree of adoption, respectively, X_i the vector of characteristics influencing the pesticides adoption behavior of rural household i. δ_m the regression coefficient of the welfare effect when rural household i selects m compared to a rural household that did not adopt pesticides. l_{im} represents unobservable characteristics that affect both rural household i selecting m and its welfare. λ_m the regression coefficient of l_{im}.

4. Data and Variables Description

4.1. Welfare Level of Rural Households

Between the 1980s and 1990s, A. Sen introduced the theory of capabilities and proposed a new approach to the concept of welfare. According to Sen, capabilities are conjunctions of potential functional activities that an individual is expected to be able to achieve, such as engaging in main productive activities, maintaining a healthy body, or having sufficient free time to share with family and friends. If an individual's welfare is determined by the functional activities he performs throughout his life, then his abilities represent real opportunities to reap benefits and the flexibility to choose from a variety of lifestyle options. To assess the benefits of functional activities, Sen considered six main factors, including living conditions, income levels, health status, education and knowledge, social situations, and psychological conditions. Based on the orientation given by Sen to the theory of welfare, this article develops a welfare index system for rural Cameroonian households that takes into account gross farm income and health status, thereby operationalizing the capability approach in a context where economic productivity and health are deeply interdependent.

The development of a composite index that combines agricultural income and health status offers a novel framework for assessing welfare in rural economies. This approach acknowledges that economic prosperity alone cannot fully capture well-being, since health critically influences both productivity and the capacity to benefit from income. Methodologically, the index relies on robust indicators: gross agricultural revenue for the economic dimension and standardized health measures such as morbidity rates, life expectancy, or self-reported health status for the social dimension. These indicators are normalized, weighted according to theoretical or empirical relevance, and aggregated into a single score. Formally, the welfare index is expressed as:

$$W_i = \alpha \frac{Income_{agri}}{Income_{\max}} + \beta \frac{Health_{score}}{Health_{\max}} \tag{10}$$

With W_i denoting the welfare index, $Income_{agri}$ the gross agricultural income, $Health_{score}$ the composite health score, and $Income_{\max}$ and $Health_{\max}$ the respective reference values used for normalization. The coefficients α and β represent the relative weights assigned to the economic and health dimensions, reflecting their theoretical importance in welfare assessment.

4.1.1. Gross Farm Income

Gross farm income is the income generated by the production and marketing of products from the producer's farm [40] [41]. It represents the difference between total gross production receipts and actual operating expenses. Expenses here include variable input costs (seed, fertilizer and pesticides purchase costs, labor costs, etc.). It differs from disposable income, which takes into account all sources of income for a farm household, including off-farm income and income from assets. According to [42] [43], it is calculated for a single crop year and generally starts with the gross product, which is the value of production estimated at the market price. Intermediate consumption (operating costs) is then subtracted to obtain the gross margin. Finally, this calculation takes into account the other income linked to the agricultural activity to obtain the gross income.

4.1.2. Health and Leisure Status of the Head of Rural Household

The health status defines the general physical and/or mental condition during a given period (in this case, the agricultural season) [44]. Participating in leisure activities helps maintain good health and can potentially improve welfare. In the literature, health status in particular is measured along different dimensions. In fact, [44] and [45] identify three main dimensions which make it possible to assess an individual's state of health:

- The medical dimension, according to which poor health corresponds to a deviation from a medical standard and results in the onset of an illness.
- The functional dimension, in which poor health is explained by limitations in activity caused by illness;
- The subjective dimension, in which the state of health is apprehended in terms of the individual's feelings. On the other hand, according to the medico-economic approach of cost-utility analysis, health status is measured by indicators such as the rate of chronic and/or acute respiratory diseases, the rate of skin diseases, and the rate of infectious diseases. In our study, we determine the health status using

the following formula:

$$Health_{score} = \gamma_1 \frac{sickdays}{sickdays_{\max}} + \gamma_2 \frac{diseasecount}{diseasecount_{\max}} + \gamma_3 \frac{selfratedhealth}{selfrated_{\max}} \quad (11)$$

$Health_{score}$ represent composite health score; is the weighting assigned to the health indicator *i*; $Sickdays$ represent the number of days the producer *i* reports being unable to work due to illness. $Diseasecount$ is the number of specific symptoms declared by the head of household. $selfratedhealth$ represents a subjective evaluation of health status by the producer; γ_1, γ_2, γ_3 are weights assigned to each indicator. By assigning weights to each indicator, this estimate takes into account the relative importance of each indicator. Secondly, by standardizing the values of each indicator, we can compare indicators that have different units of measurement. The purpose of this calculation is to provide a quantitative and global estimate of the health status of individuals in a specific population, in this case the heads of rural households. According to some references in the literature, these two variables are generally used to measure the welfare of rural households, particularly in studies related to poverty, health, and rural development [46] [47].

4.1.3. Treatment Variable

In this article, the treatment variables include pesticides adoption behavior and degree of adoption (**Table 1**). In terms of adoption, it measures the number of pesticides sub-products adopted by a rural household. For our study, chemical pesticides include three sub-product types for weed and pest control, including insecticides, fungicides, and herbicides. In a multinomial model, early adoption of pesticides refers to use before most producers, while late adoption occurs once the practice is widespread. Lower values indicate early adoption and higher values indicate late adoption. This distinction is measured by comparing individual adoption time to collective benchmarks or to the time elapsed since pesticides were introduced in the rural area, and can be formalized with the formula:

$$I_{adoption} = \frac{t_{producer} - t_{introduction}}{t_{diffusion\_\max}} \quad (12)$$

where $t_{producer}$ is the time of pesticides adoption by the producer, $t_{introduction}$ is the period of introduction of pesticides in the area, and $t_{diffusion\_\max}$ represents the time when the majority of producers adopted pesticides. For the suitability of our analysis, when a head of household adopts only one type from among the sub products listed above, the adoption degree of the household is defined as low; when the family farm adopts more than two sub products, the adoption degree of the household is defined as high.

$$D_{adoption} = \begin{cases} \text{Low} & \text{if } N_{sub} = 1 \\ \text{High} & \text{if } N_{sub} > 2 \end{cases} \quad (13)$$

Table 1. Combination of pesticides adoption choices by the head of rural household.

Adoption status		package and Combinaison	Pesticides and degree of adoption			
			Herbicides	Insecticides	Fongicides	degree
Pesti_0	1	H_0 I_0 F_0	0	0	0	//
Pesti_1	2	H_1 I_0 F_0; H_1 I_0 F_0; H_0 I_0 F_1	1	1	1	Low
	3	H_0 I_1 F_1	0	1	1	High
	4	H_1 I_0 F_1	1	0	1	High
	5	H_1 I_1 F_0	1	1	0	High
	6	H_1 I_1 F_1	1	1	1	High

4.1.4. Controlled Variable

Based on the suggestions in the literature, this article distinguishes socio-demographic variables such as the age (real age in 2024) and gender of the head of the rural household (1 = male; 0 = female), the level of instruction (actual and number of years of study), the size of the household (labor force of the household), financial status, experience (number of years spent in agriculture), and agronomic variables like land area, diversification (number of different crops on the farm), improved seeds, and frequency of pesticides spraying. Also, the paper includes as control variables the occurrence of communication with neighboring producers, cooperatives, and agricultural extension services. 7-point Likert[2] scales are used to measure those other characteristics.

4.1.5. Identification Variable

At least one control variable in the choice equation should not be included in the outcome equation in order to guarantee the identifiability of the decision equation and the outcome equation [48]. The distance (km) between the rural household and the nearest Agricultural Technology Extension Centre (CVTA) is therefore chosen as the identification variable in this paper. We analyze its robustness[3] based on the research of [49]. According to the indications of [50], the control variables of the outcome equations and the decision equations are generally identical except for the identification variable. The theoretical reasoning is that distance to a CVTA affects adoption decisions by conditioning access to information and technical support, thereby influencing the likelihood that households adopt pesticides. However, distance does not directly impact household welfare (income, health); its effect is mediated only through the adoption channel, since improvements in productivity and welfare arise from pesticides use rather than geo-

[2]The 7-point Likert scale is a survey method used to measure opinion or agreement with a statement on a scale ranging from a negative extreme to a positive extreme, passing through a neutral point.

[3]The test results illustrate the validity of the identification variable and the importance of rural households' understanding of the impacts of pesticides in the decision-making process. However, it is not significant in the result equation.

$$\chi^2 = 171(p = 0.000)$$

$$F = 1.30(p = 0.147)$$

graphical proximity itself.

4.2. Data Exploration

4.2.1. Data Resources

As part of our data resources, we focused on the central and western areas, which together make up 2 of the 5 main agro-ecological regions of Cameroon where agricultural activities are very significant [51]. Several reasons justify the choice of these two regions. Firstly, the contribution to the country's total agricultural production can reach over 80% for certain crops. Secondly, the number of rural households in both regions has experienced rapid growth, with the count of registered family farms now exceeding one million in each area. Thirdly, the incidence of agricultural pests and diseases is high in these two regions, hence the need for optimum pest and disease management to reduce their impact on production. Fourthly, since 2019, although there is no clear statistical data for the Centre region, the pesticides chemical use coverage rate of major crops has reached 35.8% [52]. These different arguments justify why these two regions have been selected for the survey, under the assumption that they will be representative.

This study was conducted in two main stages. Firstly, a preliminary research was piloted during the month of May 2024, where 60 rural households in both regions were randomly selected for interviews. Based on the initial results of this stage, some major improvements have been made to the final questionnaire. The formal survey constituted the second stage of the field study, which took place from June to August of 2024. For this phase, we adopted a three-stage random sampling approach. Firstly, we randomly selected two divisions in each region. Next, we randomly selected four subdivisions in each division. Finally, 50 rural households were randomly selected in each district of the subdivision to complete the questionnaire survey. The questionnaires were administered by two trainees and three postgraduate students, all having received capacity building in field survey techniques. We surveyed a total of 1100 rural producers. After removing a few irregularities from the questionnaires, 920 valid survey forms were ultimately retained, giving an effective data rate of 83.60%.

4.2.2. Descriptive Statistics

As illustrated in **Table 2** and **Table 3**, among the 920 rural households, 515 had adopted pesticides, accounting for 55%; 127 rural households had a low degree of pesticides adoption, accounting for 13%, and 388 rural households adopted pesticides to a high degree, accounting for 42%. These statistics on pesticides adoption among our sample align with the current situation in Cameroon. The pesticides use penetration rate is relatively high, and most households in the sample are characterized by a high degree of adoption. Considering the characteristics of rural households, **Table 2** reveals in terms of gender, instruction and age that most of the heads are men, with an average level of education and are relatively young. On average, rural households cultivate an area of 6 - 7 ha, and the household size, which represents the labor force of the household, is about 8 people. The indicators above are consistent with the survey results for family farms conducted by the Cameroon institution in charge of agriculture and rural development in 2020, demonstrating that our results are statistically representative.

Table 3 indicates that the mean values of gross farm income and level of life quality satisfaction of households that adopt pesticides are greater than those of rural households that did not adopt pesticides. Yet, in another way, the results for the mean values of health and leisure status of pesticides adopters are lower than those of households that did not adopt, revealing the potential negative effect of those products on health. These differences are significant, indicating that pesticides adoption can significantly affect the welfare of rural households in Cameroon. Nevertheless, to specify the welfare effect of rural households' pesticides adoption behaviors, a robust assessment process is essential.

Table 2. Descriptive statistics.

Group of Variables	Definition and Value Criteria	Mean	Std. Dev.
Treatment variable			
Pesticides adoption	1 = adopting; 0 = not adopting	0.55	0.41
High degree	1 = adopting ≥ 2 sub-product types; 0 = otherwise	0.42	0.32
Low degree	1 = adopting only 1 sub-product type; 0 = otherwise	0.13	0.49
Controlled variable			
Age	Actual age of head of household (2024)	45.18	14.55
Gender	1 = Male; 0 = Female	0.89	0.43
Instruction	number of years completed in formal education	8.26	6.71
Housesold_Size	Actual number of household members	8.37	2.76
Financial_status	1 = scarce; 2 = relatively scarce; 3 = neutral; 4 = relatively abundant; 6 = abundant	3.50	1.55
Experience	Number of years involved in agriculture	11.80	5.76
Exploited Land Area	Exploited land area cultivated in 2024 (ha)	6.50	40.78
Diversification	Number of crops on the farm	2.18	1.95
Pesti_frequency	Frequency of pesticides spraying	2.12	1.07
Access_Seeds	1 = the head of the rural household has access to improved seeds; 0 = otherwise	0.33	0.41
Risk_ inclination	1 = risk-averse; 2 = neutral; 3 = risk-loving	2.16	1.85
Occurrence of communication with neighbours	1 = low; 2 = relatively low; 3 = neutral; 5 = relatively high; 6 = high	3.73	1.66
Cooperatives	1 = the head of the rural household belongs to an agricultural cooperative; 0 = otherwise	1.46	0.88
Identification variable			
Agricultural Technology Extension Service (SVTA)	distance (km) between a household and the nearest SVTA	4.58	2.17

Table 3. Statistics of rural households' welfare indicators.

Variable	Value Criteria	Pesti_1 (n = 505)		Pesti_0 (n = 405)		Difference
		Mean	Std. Dev	Mean	Std. Dev.	
Gross farm income	Net income from farming per ha (hundred thousand XAF francs per ha)	6.55	2.01	4.72	2.48	0.000***
Health status	1 = bad; 2 = fair; 3 = good	1.02	0.91	2.94	0.80	0.000***
Leisure status	1 = scarce; 2 = neutral; 3 = abundant	1.06	1.21	2.03	1.71	0.098**
Satisfaction with quality of life	1 = dissatisfied; 2 = neutral; 3 = satisfied	2.48	1.32	1.06	1.0	0.000***

Significant at the 1% level ***p < 0.01, at the 5% level **p < 0.05, and at the 10% level *p < 0.1.

5. Results and Discussion

5.1. ESR Model

Based on Table 4, the hypothesis that the decision equation and the outcome equation are independent is significantly rejected by the Wald χ^2 test. Also, ρ_0 and ρ_1 are significantly different from zero at the 5% level, specifying that the decision to apply pesticides and the welfare conditions of rural households are both influenced by non-observable characteristics. From the estimation results of the pesticides adoption decision, gender, level of instruction, household size, financial status, exploited land area, diversification of crops in the farm, and pesticides frequency significantly influence rural households' pesticides adoption behavior. However, head of household age, agricultural experience, access to improved seeds, and access to agricultural technology extension services do not have a significant effect on this decision. This result can be explained by different reasons. Firstly, most of the heads of rural households in the study area are relatively young, with an inconsequential variance in age. Also, most producers are dedicated to adopting chemical pesticides when their exploited land area and crop diversification exceed a certain stage, denoting that they have reached the standards for scale recognized by the local administration.

The results from the estimation of the outcome equation show that, based on the probability for the household to adopt and use chemical pesticides, the level of instruction of the head of household, the financial status of the household, and access to agricultural technology extension services have a significant positive impact on the level of welfare, while household head age, household size (labor force size), exploited land, pesticides frequency, and risk preference have a significant negative impact. The reasons are as follows. Firstly, the more a head of a rural household receives formal instruction, the better his abilities in decision-making, allocation of resources, and adoption of relevant support policies will be. As a consequence, household welfare will improve. Also, a household with good financial status tends to have access to better socioeconomic commodities than others, and is expected to be more satisfied with their quality of life. Moreover, the implications and determination of local agricultural technology extension services to assist rural households in managing and gaining access to agricultural technologies can undoubtedly improve their socioeconomic situation. Furthermore, a greater supply of household labor force improves agricultural production and available leisure time while also increasing the continuity of cultivation.

The ageing of a producer's head of household has a negative impact on their welfare through two main mechanisms. Advanced age is associated with a gradual decline in learning and cognitive abilities, which reduces their management skills. This ultimately leads to a decline in the economic performance of their family farms. Older producers are more prone to health problems. This deterioration in their health directly leads to a decline in their overall satisfaction with their quality of life. In addition, several other variables, including gender, risk preference, pesticides spraying frequency, and cultivated land area, have no significant impact on the well-being of rural households, regardless of their level of pesticides use.

5.2. Average Treatment Effects on Households' Welfare

Table 5 presents the results related to the average treatment effect of chemical pesticides adoption on the main indicators of rural household welfare. Based on these results, the welfare treatment effect for households that adopted chemical pesticides is 0.705, and the welfare treatment effect value for households that did not adopt pesticides is 0.630. The counterfactual examination indicates that if rural households adopting chemical pesticides had not used this technology, the value of the treatment effect on their welfare would have been 0.587. Conversely, the counterfactual estimate suggests that if non-adopting households had used this technology, the treatment effect on welfare would have been 0.498. Consequently, the estimated Average Treatment Effect on the Treated (ATT) for pesticides adopters is 0.092, while the Average Treatment Effect on the Untreated (ATU) is 0.073. Furthermore, the analysis reveals that if rural households currently adopting pesticides were to abandon this production technology, it would result in a welfare loss of 32.62%. Conversely, if non-adopting households were to embrace this agricultural technology, their welfare level is projected to increase by 21.37%. This finding strongly suggests that the use of pesticides contributes significantly to improving the welfare of rural households.

5.3. Multinomial Treatment Effects Model

Table 6 exposes the results of the multinomial treatment effects model estimation[4]. Compared to households that did not adopt chemical pesticides, the welfare of households that adopted high-dose and low-dose pesticides increased by 20.72% and 15.23%, respectively. This highlights an intensity relationship: the degree of pesticides adoption modulates the level of welfare, such that high adoption has a greater

[4]The estimation outcome for the decision equation within the multinomial treatment effects model is briefly described due to space limitations.

effect on welfare than low adoption. Furthermore, compared to rural households that did not adopt pesticides, those that introduced them early or late saw improvements in their welfare of 5.90% and 7.37%, respectively. These results suggest that the timing of adoption influences the magnitude of gains, with late adopters likely benefiting from lessons learned from the initial failures of early adopters.

Table 4. The endogenous switching regression model estimations.

Variables	Decision equation	Outcome equation	
		Pesti_1 (n=505)	Pesti_0 (n=405)
Age	−0.081* (0.10)	−0.006** (0.004)	−0.014***(0.000)
Gender	0.039* (0.010)	0.037* (0.007)	0.028 (0.135)
Instruction	0.046* (0.020)	0.042* (0.010)	0.022*** (0.000)
Housesold_Size	−0.077** (0.051)	0.064*** (0.003)	0.092 (0.030)
Financial_status	0.066*** (0.000)	0.051* (0.011)	0.029* (0.012)
Experience	0.093 (0.148)	0.101 (0.194)	0.199 (0.178)
Exploited Land Area	−0.157* (0.101)	0.032*** (0.000)	−0.061 (0.049)
Diversification	0.043** (0.019)	0.086 (0.060)	0.115 (0.095)
Pesti_frequency	−0.088* (0.049)	0.098** (0.000)	0.034 (0.018)
Access_Seeds	0.782 (0.927)	0.096 (0.060)	0.227 (0.095)
Risk preference	−0.209** (0.091)	0.082 (0.028)	0.097***(0.000)
Occurrence of communication with neighbours	0.079 (0.160)	0.104 (0.182)	0.158 (0.181)
Cooperatives	0.673 (0.175)	0.109***(0.000)	0.201(0.539)
Agricultural Technology Extension Service (SVTA)	0.093** (0.049)	0.093*** (0.043)	0.072* (0.018)
Constant	−0.419***(0.000)		
σ_{μ_0} ; σ_{μ_1}			
ρ_0 ; ρ_1		−0.789*** (0.000)	−0.355*** (0.000)
Wald χ^2			
Log likelihood	−568.407		−476.449
F-statistics		691.425***	783.170***
Observations	920		

Significant at the 1% level ***p < 0.01, at the 5% level **p < 0.05, and at the 10% level *p < 0.1.

Table 5. Average treatment effects on households' welfare.

Outcome variable	Household categories and treatment effects	Pesticides use decision		ATT/ATU	t-statistics	ATT/ATU (%)
		Pesti_1 (n = 505)	Pesti_0 (n = 405)			
household Welfare level	pesticides adopters (ATT)	0.705 (0.341)	0.587 (0.204)	0.092***	0.000	32.62
	pesticides non-adopters (ATU)	0.630 (0.154)	0.498 (0.186)	0.073*	0.102	21.37

P-values are in parentheses. indicates 1%, is 5%, and is 10% significance levels, respectively. The standard error values are in brackets.

Table 6. Estimates of multinomial treatment effects.

Variable	Model 1 (Pesticides adoption degree)	Variable	Model 2 (Pesticides adoption timing)
High degree of pesticides adoption	0.207*** (0.001)	Earlier pesticides adoption	0.073*** (0.001)
Low degree of pesticides adoption	0.152* (0.109)	Later pesticides adoption	0.059** (0.041)
Age	−0.005*** (0.002)	Age	−0.003** (0.033)
Gender	0.028 (0.745)	Gender	0.086* (0.09)
Instruction	0.063*** (0.005)	Instruction	0.041*** (0.000)
Housesold_Size	0.017 (0.026)	Housesold_Size	0.135 (0.093)
Financial_status	0.046*** (0.001)	Financial_status	−0.069** (0.050)
Experience	−0.046 (0.78)	Experience	0.081 (0.419)
Exploited Land Area	0.089** (0.021)	Exploited Land Area	0.018* (0.091)
Diversification	0.036* (0.103)	Diversification	0.022** (0.0051)
Pesti_frequency	0.061** (0.005)	Pesti_frequency	0.041 (0.075)
Access_Seeds	−0.088 (0.096)	Access_Seeds	0.021*** (0.000)
Risk_ inclination	0.017 (0.027)	Risk_ inclination	0.159 (0.089)
Occurrence of communication with neighbours	0.311 (0.218)	Occurrence of communication with neighbours	0.145 (0.073)
Cooperatives	0.712* (0.101)	Cooperatives	−0.007* (0.010)
Agricultural Technology Extension Service (SVTA)	0.045 (0.428)	Agricultural Technology Extension Service (SVTA)	5.095*** (0.000)
λ (high degree of pesticides adoption)	0.836*** (0.000)	λ (earlier pesticides adoption)	0.683** (0.007)
λ (low degree of pesticides adoption)	0.787** (0.377)	λ (later pesticides adoption)	0.147* (0.010)
constant	4.037*** (0.871)	constant	5.092*** (0.000)
No of obs	920	No of obs	920

Significant at the 1% level ***$p < 0.01$, at the 5% level **$p < 0.05$, and at the 10% level *$p < 0.1$.

6. Conclusion and Agricultural Policy Recommendations

This article applies a dual ESRM and MTEM estimation to assess the welfare implications of adopting and/or not adopting chemical pesticides among rural households in Cameroon. It also quantifies the discriminatory effects on welfare associated with the intensity and frequency of adoption. The ESRM estimation indicates that pesticides adoption contributes to improving household welfare, while the MTEM results show that welfare gains depend strongly on both the intensity and the timing of adoption. Specifically, households that adopt pesticides intensively and those that adopt later in the season achieve the most significant welfare improvements. Based on these results, the main findings of this study provide both a theoretical and empirical basis for supporting agricultural policy based on expanding pesticides use in Cameroon. It contributes significantly to discussions on modernizing the agricultural sector and improving welfare conditions in rural areas. The study also outlines the implications for agricultural and social policies, according to which the strategy for the dissemination of chemical pesticides should be expanded and improved to incorporate environmental and health aspects. These findings have direct policy implications: interventions should be tailored to encourage higher adoption intensity and to support late adopters, who appear to benefit most. For example, policies on access to credit, training, and extension services should prioritize households adopting later, in order to maximize welfare gains and reduce operational risks. Furthermore, it would be appropriate to strengthen training for producers by consolidating efforts to re-educate farm managers, by emphasizing the creation of local institutions for the dissemination of innovation; this would promote the development of a robust system for the dissemination of biopesticides. This would strengthen the internal and external conditions for adoption and the external environment of the household, and reduce barriers to pesticides adoption. Secondly, rural households should be encouraged to increase their level of biopesticides adoption and provide greater subsidies to producers who use sufficient quantities of biopesticidess compared to those who do not use them. This would encourage those who do not use them to increase their use. In addition, full advantage should be taken of local cooperatives to spread the word about the benefits of judicious pesticides use on the economic welfare of rural households. Furthermore, policymakers should target their interventions more specifically at farms that adopted pesticides earlier. Finally, when it comes to developing policies on access to credit, quality education, and training, priority should be given to rural households that adopt chemical pesticides later in order to minimize latent operational risks. Beyond this, several complementary recommendations emerge: Targeted extension programs should differentiate between early and late adopters, offering specialized training to late adopters to help them consolidate the welfare gains they achieve. Graduated subsidy schemes could reward households that increase adoption intensity, ensuring that minimal users are incentivized to scale up their practices. Risk management instruments (such as crop insurance or safety nets) should be designed for early adopters, who may face higher uncertainty and lower immediate welfare gains compared to late adopters. Strengthening cooperatives and producer organizations can facilitate collective learning, allowing late adopters to benefit from peer experiences while encouraging intensive users to share best practices. Environmental and health safeguards must be integrated into dissemination strategies, ensuring that the welfare gains from intensive adoption do not come at the expense of sustainability. Credit and input supply policies should be sequenced to align with adoption timing, giving late adopters priority access to resources when their welfare gains are most pronounced. By linking recommendations directly to the study's findings on adoption intensity and timing, this analysis provides a stronger empirical foundation for agricultural modernization policies in Cameroon, while also highlighting the importance of tailoring interventions to household adoption behavior.

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Credit Authorship Contribution Statement

Kaldjob Mbeh Christian and Douya Emmanuel conceived the original idea. Kaldjob Mbeh Christian supervised and drafted the manuscript with support from Douya Emmanuel. Kaldjob Christian has written the original draft. Kaldjob Mbeh Christian reviewed and edited the manuscript. Kaldjob Mbeh Christian and Douya Emmanuel proceeded to data curation, methodology, and empirical analysis. All authors provided critical feedback and helped shape the research, analysis, and manuscript. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

All data generated during this study will be made available upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Jmaii, A. (2025) Microeconometric Analysis of Energy Poverty and Urban-Rural Welfare Disparities in Tunisia: Implications for Sustainable Development Policy. *Energy Policy*, **203**, Article Number 114636. https://doi.org/10.1016/j.enpol.2025.114636

[2] Bezu, S. and Holden, S. (2014) Are Rural Youth in Ethiopia Abandoning Agriculture? *World Development*, **64**, 259-272. https://doi.org/10.1016/j.worlddev.2014.06.013

[3] Asfaw, S. and Shiferaw, B.A. (2010) Technology Adoption and Poverty in East Africa. African Association of Agricultural Economists (Cape Town, South Africa), AgEcon Search, Vol. 48, 1-31.

[4] Asongu, S.A. and Le Roux, S. (2018) Understanding Sub-Saharan Africa's Extreme Poverty Tragedy. *International Journal of Public Administration*, **42**, 457-467. https://doi.org/10.1080/01900692.2018.1466900

[5] Djoumessi, Y. (2020) Essais sur la Productivité Agricole en Afrique Sub-Saharienne. Ph.D. Thesis, Université de Dschang. https://hal.archives-ouvertes.fr/tel-02867792

[6] Lydie, B.T., Christian Bernard, K.M. and André, N.N. (2021) Assessment of a New Weeding Technology as a Solution for the Sustainable Welfare of Rice Producers in Cameroon. In: Leal Filho, W., Pretorius, R. and de Sousa, L.O., Eds., *Sustainable Development in Africa*, Springer, 461-476. https://doi.org/10.1007/978-3-030-74693-3_25

[7] Bassala, O., Paul, J., Dugue, P., Granie, A.M. and Vunyungah, M. (2015) Herbicide Use and Perceptions. IJASRA (Canada). https://agritrop.cirad.fr/579836/

[8] INS (2015) Agriculture. Annuaire statistique du Cameroun. Institut National de la Statistique. Institut National de la Statistique du Cameroun. https://ins-cameroun.cm/2015/

[9] Mahob, R., Ndoumbe-Nkeng, M., Ten Hoopen, G., Dibog, L., Nyasse, S., Rutherford, M., *et al.* (2015) Pesticides Use in Cocoa Sector in Cameroon: Characterization of Supply Source, Nature of Actives Ingredients, Fashion and Reasons for Their Utilization. *International Journal of Biological and Chemical Sciences*, **8**, 1976-1989. https://doi.org/10.4314/ijbcs.v8i5.3

[10] Dorothy, E., Mbei, T. and Tarla, D. (2019) Contribution of Phytosanitary Products to the Revenue of Market Garden Farmers in Mezam Division, North West Region of Cameroon. https://www.researchgate.net/publication/333059533

[11] Ndoumbe-Nkeng, M., Cilas, C., Nyemb, E., Nyasse, S., Bieysse, D., Flori, A., *et al.* (2004) Impact of Removing Diseased Pods on Cocoa Black Pod Caused by Phytophthora Megakarya and on Cocoa Production in Cameroon. *Crop Protection*, **23**, 415-424. https://doi.org/10.1016/j.cropro.2003.09.010

[12] Pouokam, G., Lemnyuy Album, W., Ndikontar, A. and SIDATT, M. (2017) A Pilot Study in Cameroon to Understand Safe Uses of Pesticides in Agriculture, Risk Factors for Farmers' Exposure and Management of Accidental Cases. *Toxics*, **5**, Article 30. https://doi.org/10.3390/toxics5040030

[13] Ehiakpor, D.S., Danso-Abbeam, G., Dagunga, G. and Ayambila, S.N. (2019) Impact of Zai Technology on Farmers' Welfare: Evidence from Northern Ghana. *Technology in Society*, **59**, Article ID: 101189. https://doi.org/10.1016/j.techsoc.2019.101189

[14] Danso-Abbeam, G. and Baiyegunhi, L.J.S. (2018) Welfare Impact of Pesticides Management Practices among Smallholder Cocoa Farmers in Ghana. *Technology in Society*, **54**, 10-19. https://doi.org/10.1016/j.techsoc.2018.01.011

[15] Antle, J.M. (2015) Pesticides Policy, Production Risk, and Producer Welfare: An Econometric Approach to Applied Welfare Economics. Routledge. https://www.routledge.com

[16] Johnston, B.F. and Mellor, J.W. (1961) The Role of Agriculture in Economic Development. *The American Economic Review*, **51**, 566-593. https://www.jstor.org/stable/1812786

[17] Pelletier, G. (2009) Théorie du bien-être et politique économique. *L'Actualité économique*, **54**, 59-76. https://doi.org/10.7202/800758ar

[18] Boehm, S. (2002) Is There Progress in Economics? Knowledge, Truth and the History of Economic Thought. Edward Elgar. https://ideas.repec.org/b/elg/eebook/2403.html

[19] Vilfredo, P. (1971) Manual of Political Economy. https://cir.nii.ac.jp/crid/1971430859775275812

[20] Pigou, A.C. (1920) The Economics of Welfare. 4th Edition, Macmillan. https://archive.org/details/in.ernet.dli.2015.460552

[21] Baujard, A. (2011) L'Économie du bien-être est morte. Vive l'économie du bien-être. https://doi.org/10.3917/edmat.campa.2017.01.0077

[22] Marshall, A. (1890) "Some Aspects of Competition." The Address of the President of Section F—Economic Science and Statistics—Of the British Association, at the Sixtiet Meeting, Held at Leeds, in September, 1890. *Journal of the Royal Statistical Society*, **53**, 612-643. https://doi.org/10.2307/2979546

[23] Gao, Y., Niu, Z., Yang, H. and Yu, L. (2019) Impact of Green Control Techniques on Family Farms' Welfare. *Ecological Economics*, **161**, 91-99. https://doi.org/10.1016/j.ecolecon.2019.03.015

[24] Lange, O. (1942) The Foundations of Welfare Economics. *Econometrica*, **10**, 215-228. https://doi.org/10.2307/1905465

[25] Hicks, J.R. (1939) The Foundations of Welfare Economics. *The Economic Journal*, **49**, 696-712. https://doi.org/10.2307/2225023

[26] Kaldor, N. (1939) Welfare Propositions of Economics and Interpersonal Comparisons of Utility. *The Economic Journal*, **49**, 549-552. https://doi.org/10.2307/2224835

[27] Sen, A. (1982) Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford University Press. https://doi.org/10.1093/0198284632.001.0001

[28] Perge, E. and McKay, A. (2016) Forest Clearing, Livelihood Strategies and Welfare: Evidence from the Tsimane' in Bolivia. *Ecological Economics*, **126**, 112-124. https://doi.org/10.1016/j.ecolecon.2016.03.017

[29] Mmbando, F.E., Wale, E.Z. and Baiyegunhi, L.J.S. (2015) Welfare Impacts of Smallholder Farmers' Participation in Maize and Pigeonpea Markets in Tanzania. *Food Security*, **7**, 1211-1224. https://doi.org/10.1007/s12571-015-0519-9

[30] Deng, Z.T. and Kang, J.J. (2025) Study on the Impact of Land Transfer on Farmers' Welfare: Theoretical and Empirical Evidence from China. *Land*, **14**, 2384. https://doi.org/10.3390/land14122384

[31] Miao, S. (2014) Analysis of the Effect of Grain Price Fluctuation on Welfare. *Resources Science*, **36**, 370-378.

[32] Li, H., Huang, X., Kwan, M., Bao, H.X.H. and Jefferson, S. (2015) Changes in Farmers' Welfare from Land Requisition in the Process of Rapid Urbanization. *Land Use Policy*, **42**, 635-641. https://doi.org/10.1016/j.landusepol.2014.09.014

[33] Sen, A. (2001) Development as Freedom. Anchor. https://kuangaliablog.wordpress.com/wp-content/uploads/2017/07/amartya_kumar_sen_development_as_freedombookfi.pdf

[34] Tambo, J.A. and Wünscher, T. (2017) Farmer-led Innovations and Rural Household Welfare: Evidence from Ghana. *Journal of Rural Studies*, **55**, 263-274. https://doi.org/10.1016/j.jrurstud.2017.08.018

[35] Wordofa, M.G., Hassen, J.Y., Endris, G.S., Aweke, C.S., Moges, D.K. and Rorisa, D.T. (2021) Adoption of Improved Agricultural Technology and Its Impact on Household Income: A Propensity Score Matching Estimation in Eastern Ethiopia. *Agriculture & Food Security*, **10**, Article No. 5. https://doi.org/10.1186/s40066-020-00278-2

[36] Mendola, M. (2007) Agricultural Technology Adoption and Poverty Reduction: A Propensity-Score Matching Analysis for Rural Bangladesh. *Food Policy*, **32**, 372-393. https://doi.org/10.1016/j.foodpol.2006.07.003

[37] Fischer, E. and Qaim, M. (2012) Linking Smallholders to Markets: Determinants and Impacts of Farmer Collective Action in Kenya. *World Development*, **40**, 1255-1268. https://doi.org/10.1016/j.worlddev.2011.11.018

[38] Ma, W. and Abdulai, A. (2016) Does Cooperative Membership Improve Household Welfare? Evidence from Apple Farmers in China. *Food Policy*, **58**, 94-102. https://doi.org/10.1016/j.foodpol.2015.12.002

[39] Tanko, M., Amfo, B. and Shafiwu, A.B. (2023) Social Norms Perspective of Agriculture Technology Adoption and Welfare in Ghana: Extending Multinomial Endogenous Treatment Effect Model. *Technology in Society*, **74**, Article ID: 102324. https://doi.org/10.1016/j.techsoc.2023.102324

[40] Butault, J.P., Delame, N. and Lerouvillois, P. (2009) Activité extérieures et revenus des ménages agricoles. *Economie Rurale*, 75-90. http://journals.openedition.org/economierurale/139

[41] Deaton, A. (1997) The Analysis of Household Surveys: A Microeconometric Approach to Development Policy. The World Bank. https://doi.org/10.1596/0-8018-5254-4

[42] Vodouhê, F.G., Adégbidi, A., Coulibaly, O. and Sinsin, B. (2011) Parkia Biglobosa (Jacq.) R. Br. ex Benth. Harvesting as a Tool for Conservation and a Source of Income for Local People in Pendjari Biosphere Reserve. *Acta Botanica Gallica*, **158**, 595-608.

[43] Becerril, J. and Abdulai, A. (2010) The Impact of Improved Maize Varieties on Poverty in Mexico: A Propensity Score-Matching Approach. *World Development*, **38**, 1024-1035. https://doi.org/10.1016/j.worlddev.2009.11.017

[44] Arweiler, D. (2002) L'Économie face à la santé. Université de Montréal.

[45] Blaxter, M. (1989) A Comparison of Measures of Inequality in Morbidity. *Health Inequalities in European Countries*, **51**, 1173-1182.

[46] World Bank (2018) Annual Report of the World Bank. https://documents1.worldbank.org/curated/en/630671538158537244/pdf/The-World-Bank-Annual-Report-2018.pdf

[47] FAO (2020) L'état de la sécurité alimentaire et de la nutrition dans le monde: Renforcer la résilience face aux changements climatiques pour la sécurité alimentaire et la nutrition.

[48] Coromaldi, M., Pallante, G. and Savastano, S. (2015) Adoption of Modern Varieties, Farmers' Welfare and Crop Biodiversity: Evidence from Uganda. *Ecological Economics*, **119**, 346-358. https://doi.org/10.1016/j.ecolecon.2015.09.004

[49] Di Falco, S., Veronesi, M. and Yesuf, M. (2011) Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. *American Journal of Agricultural Economics*, **93**, 829-846. https://doi.org/10.1093/ajae/aar006

[50] Liu, T.S. (2017) The Happiness Effect of Farmers' Cooperatives: An Endogenous Switching Regression Analysis. *China Rural Survey*, **4**, 32-42.

[51] Temple, L. (2001) Quantification des productions et des échanges de fruits et légumes au Cameroun. *Cahiers Agricultures*, **10**, 87-94. https://revues.cirad.fr/index.php/cahiers-agricultures/article/view/30284

[52] Brunelle, T. and Bayiha, G.D.L.P. (2025) Economic Drivers of Pesticide Use in Cameroon. *Cahiers Agricultures*, **34**, Article No. 29. https://doi.org/10.1051/cagri/2025028