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Abstract

Agricultural commercialization is widely promoted as a pathway to rural transformation, yet the determinants of commercialization intensity and its welfare implications remain contested, particularly in climate-vulnerable, land-constrained settings and fragmented market settings. This study examines the threshold-varying determinants of oilseed commercialization and its causal effects on multidimensional food security among smallholder groundnut and soybean producers in East and West Hararghe, Ethiopia. Using cross-sectional data from 383 producers across six districts, commercialization intensity was measured using the Household Commercialization Index (HCI) and classified market participations into four ordered categories where, 30.03% of subsistence-oriented, 22.72% semi-commercialized, 25.07% of commercialized, and 22.19% of high-intensity commercialized. A generalized ordered logit model (`gologit2`) was employed to identify threshold-specific determinants, while inverse probability weighted regression adjustment (IPWRA) and generalized propensity score (GPS) approaches were used to estimate welfare effects across the Food Consumption Score (FCS), Household Dietary Diversity Score (HDDS), and Reduced Coping Strategies Index (rCSI). The generalized ordered logit model was statistically significant (Wald $\chi^2 = 148.54$, $p < 0.001$; pseudo-$R^2 = 0.258$). Production volume emerged as a major determinant of high-intensity commercialization, with each additional 100 kg associated with a 5-percentage-point increase in the probability of reaching the highest commercialization tier (AME = 0.0005 per kg, $p < 0.001$). Compared with soybean producers, groundnut producers were 14.55 percentage points more likely to achieve high-intensity commercialization ($p = 0.023$), while access to extension services increased this probability by 13.69 percentage points ($p = 0.030$). Formal education was negatively associated with high-intensity commercialization (AME = −0.1252, $p = 0.009$), as was access to credit at the 10% significance level (AME = −0.0736, $p = 0.100$). The IPWRA estimates revealed heterogeneous food-security effects across commercialization tiers. Transitioning from subsistence to semi-commercialization significantly improved FCS (ATE = 0.0802, $p = 0.006$), whereas the effects on HDDS and rCSI were statistically insignificant across all tiers. These findings suggest that the welfare benefits of oilseed commercialization are neither uniform nor automatic. Although initial market engagement may improve food consumption, higher commercialization intensity alone does not ensure greater dietary diversity or significantly reduce food-related coping strategies. Policies should therefore prioritize production expansion, accessible extension services, and stronger market linkages while complementing commercialization with dietary diversification initiatives and improved access to diverse foods in local markets.

Keywords: Agricultural commercialization; Generalized Ordered Logit (gologit2); Multi-valued IPWRA; Food security; Cash-crop paradox; Hararghe, Ethiopia.

1. Introduction

Across Sub-Saharan Africa, agriculture remains the principal driver of rural employment, smallholder livelihoods, and industrial raw material supply, making it foundational to regional poverty reduction and food security strategies (FAO, 2025; Wiggins, 2018; Alston *et al.,* 2014). However, agricultural transformation depends not merely on expanding aggregate production, but on optimizing smallholder market integration and value capture. Consequently, evaluating how commercialization patterns shape multidimensional welfare is critical for designing inclusive, nutrition-sensitive agricultural policies.

In Ethiopia, agriculture anchors the national economy, contributing 34% to 35% of national GDP (NBE, 2023). The sector absorbs nearly 80% of the active labor force, generates 75% of export earnings, and supplies up to 70% of raw inputs to domestic agro-processing industries (MoA, 2022; USAID, 2021). Smallholders form the backbone of this agrarian structure, managing over 90% of cultivated land and generating the majority of domestic output (Temesgen and Aweke, 2023). However, conventional rural development frameworks routinely treat smallholders as passive raw commodity suppliers rather than vertically integrated agribusiness actors (Legesse *et al.,* 2024). Excluding smallholders from downstream value-adding activities such as grading, modern storage, processing, and contractual coordination confines them to volatile, informal spot markets (World Bank, 2023; Barrett, 2008). In environments characterized by spatial fragmentation, deficient physical infrastructure, and price information asymmetries, this uncoordinated disposal aggravates rural poverty and food insecurity (Girma *et al.,* 2023; Da Silva and Trienekens, 2007). Transitioning toward structured, multi-channel value chain integration is therefore essential to ensure commercial production yields tangible welfare gains (Swinnen and Kuijpers, 2019; Arias *et al.,* 2013).

Despite this strategic imperative, agricultural policy in developing regions has long operated under the unverified paradigm that yield maximization and primary market entry automatically guarantee improved smallholder welfare (World Bank, 2023). Historically, public interventions heavily prioritized aggregate output growth and binary market participation as primary mechanisms for hunger reduction (Gebissa and Geremew, 2022; Bedeke *et al.,* 2020; FAO, 2008). Yet, this supply-side focus overlooks structural market failures and gives rise to the commercialization food

security paradox: while reallocating land toward high value commercial crops boosts nominal cash earnings, it forces severe resource trade-offs in land-constrained systems by diverting land and labor away from subsistence staple production (Oyka *et al.,* 2020; Sabates-Wheeler *et al.,* 2018). Heightened commercialization increases household reliance on local retail food systems, exposing vulnerable families to price shocks, food inflation, and pre-harvest lean-period deficits whenever cash earnings fail to compensate for lost subsistence food buffers (Ickowitz et al., 2019; Jemal and Kim, 2014).

Crucially, the magnitude and direction of these welfare impacts depend heavily on the commercialization intensity achieved by the farm household. Conventional empirical models treat market participation as a static binary decision (sellers vs. non-sellers), concealing structural gradients and household heterogeneity (Tabe-Ojong and Geffersa, 2024; Barrett *et al.,* 2020; Usman *et al.,* 2021; Bedeke *et al.,* 2020; Bezu *et al.,* 2012). Classifying a household selling a minor surplus identically to one commercializing the majority of its harvest obscures how socioeconomic, institutional, and spatial barriers operate across distinct intensity thresholds (Williams, 2006). Furthermore, empirical evaluations relying on unidimensional proxies fail to capture how commercialization intensity affects the multidimensional pillars of food security: availability, access, utilization, and stability (HLPE, 2020; FAO, 2008). These dynamics are acutely pronounced in eastern Ethiopia specifically within the Hararghe highlands where smallholders operate under severe structural constraints, including high demographic pressure, plot fragmentation, and climate variability (Sani *et al.,* 2022).

Oilseeds constitute the third largest agricultural export commodity group in Ethiopia, generating between 15% and 20% of national agricultural export earnings, primarily through raw sesame and high-grade groundnut shipments (Alemaw and Gurmu, 2023; NBE, 2023; Gebreyesus et al., 2021). Building upon this macro-level trade significance, oilseeds directly align with Ethiopia's broader agricultural commercialization agenda, which prioritizes market-oriented production, stronger value chain integration, and enhanced smallholder incomes through strategic public frameworks such as the Agricultural Commercialization Clusters (ACC) initiative (ATA, 2019; ATI, 2023). Within this national transformation framework, edible oilseeds most notably groundnut (*Arachis hypogaea*), sesame (*Sesamum indicum*), and soybean (*Glycine max*) are explicitly targeted by the Ethiopian Agricultural Transformation Institute as priority high-value commodities positioned to

stimulate domestic edible oil processing, expand foreign exchange earnings, and reinforce rural food security (ATI, 2023; MoA, 2022; ATA, 2019).

Crucially, these national priority objectives intersect with localized livelihood realities in the East and West Hararghe zones of eastern Ethiopia, where semi-arid conditions and recurrent moisture stress constrain smallholder production choices (Sani *et al*., 2022). Under these moisture-stressed conditions, groundnut and soybean cultivation offers an indispensable opportunity to diversify smallholder livelihoods, generate cash income, and strengthen household purchasing power (Tafere *et al.,* 2022; MoA, 2021). However, realizing these commercial benefits remains challenging. Smallholders face limited access to certified inputs, inadequate storage infrastructure, weak market linkages, and severe price information asymmetries (Achamyelh and Hailemariam, 2020; Wubetu *et al.,* 2016). Coupled with acute post-harvest liquidity constraints, these barriers compel farmers into distress sales immediately after harvest when local market prices are lowest. Furthermore, entrenched market intermediaries and governance inefficiencies within local farmer cooperatives restrict smallholders' bargaining power and prevent effective value capture (Girma *et al.,* 2024; Legesse *et al.,* 2024).

Moreover, when groundnut and soybean production diverts scarce household land and labor away from staple food crops, the net welfare impact hinges on whether commercialization generates sufficient and timely income to offset lost subsistence food buffers. In the presence of thin, volatile retail markets, increased oilseed production and sales do not automatically translate into improved dietary diversity or reduced reliance on food-related coping strategies, particularly during the pre-harvest lean season (Almaz *et al*., 2024; Abebaw and Dereje, 2013). Despite growing research on agricultural commercialization, four critical knowledge gaps persist regarding smallholder oilseed systems in Hararghe:

1. **Contextual Gap:** Existing empirical literature has predominantly focused on agronomic production performance and primary market entry decisions, offering limited insight into how groundnut and soybean commercialization affects multidimensional food security in climate-vulnerable, moisture-stressed smallholder systems.

2. **Methodological Gap:** Conventional evaluations rely heavily on binary seller–non-seller models, failing to account for commercialization intensity gradients, non-linear welfare effects, and continuous household selection heterogeneity.
3. **Conceptual and Policy Gap:** Policy frameworks routinely assume linear welfare gains from commercialization, ignoring potential trade-offs driven by crop specialization, heightened reliance on volatile retail food markets, and pre-harvest liquidity traps.
4. **Outcome-Measurement Gap:** Previous research rarely conducts joint assessments of complementary multidimensional food security indicators specifically the Food Consumption Score (FCS), Household Dietary Diversity Score (HDDS), and Reduced Coping Strategies Index (rCSI) which together capture changes in caloric consumption, dietary quality, and behavioral coping mechanisms.

Against this background, the central empirical question addressed by this study is whether, and under what conditions, greater commercialization of groundnut and soybean improves multidimensional food security among smallholder households in Hararghe, Ethiopia. Specifically, this study examines the socio-demographic, institutional, and spatial drivers of oilseed commercialization intensity and estimates its causal relationship with household FCS, HDDS, and rCSI. By analyzing variations across commercialization intensity levels and controlling for selectivity and confounding biases through a robust impact-evaluation strategy, this research establishes whether the economic benefits of commercialization outweigh its potential food-security trade-offs. Ultimately, these findings provide context-specific empirical evidence to guide the design of inclusive, nutrition-sensitive agricultural policies that strengthen smallholder market integration while safeguarding household food security.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in west and east Hararghe zones, eastern Oromia, Ethiopia. Geographically, West Hararghe and East Hararghe are located approximately 200 km and 400 km east of the national capital, Addis Ababa, respectively. The study area spans latitudes 7°00′00″ N to 10°00′00″ N and longitudes 40°00′00″ E to 43°00′00″ E. Specifically, West Hararghe is centered near 8°40′ N latitude and 40°51′ E longitude, whereas East Hararghe extends from 7°36′ N to 9°41′ N latitude and 41°18′ E to 43°00′ E longitude. The topography across the study area is highly varied, with elevations ranging from 1,000 to 3,405 meters above sea level. Agro-ecologically divided into lowlands (comprising 30–40% of the landmass), midlands (35–45%), and highlands (15–20%) (CSA, 2021). Rural households are characteristically large, with an average family size of approximately seven members.

Agriculture is the backbone of the local economy and the primary foundation for smallholder livelihoods. Far beyond direct agricultural yields, the sector drives broader structural transformation by powering rural off-farm economies through commodity aggregation, agro-processing, and market trade. The principal staple crops grown include sorghum, maize, sweet potatoes, wheat, barley, and pulses, while cash crop production led by oilseeds (groundnuts and soybeans), khat, potatoes, onions, and shallots provides critical cash income (Adem and Wako, 2024). Livestock husbandry complements crop cultivation by supplying draft power, household income, and asset security. Despite this agricultural potential, smallholders in the Hararghe face persistent structural vulnerabilities, including erratic rainfall patterns, acute moisture stress, and restricted market access.

Figure 1 presents the spatial orientation of the study area: the top-left inset depicts the location of the Oromia region within Ethiopia; the bottom-left inset highlights the East and West Hararghe; and the main map panel highlights the six specific study districts (Babile, Fedis, and Gursum in East Hararghe; Chiro, Mieso, and Tulo in West Hararghe).

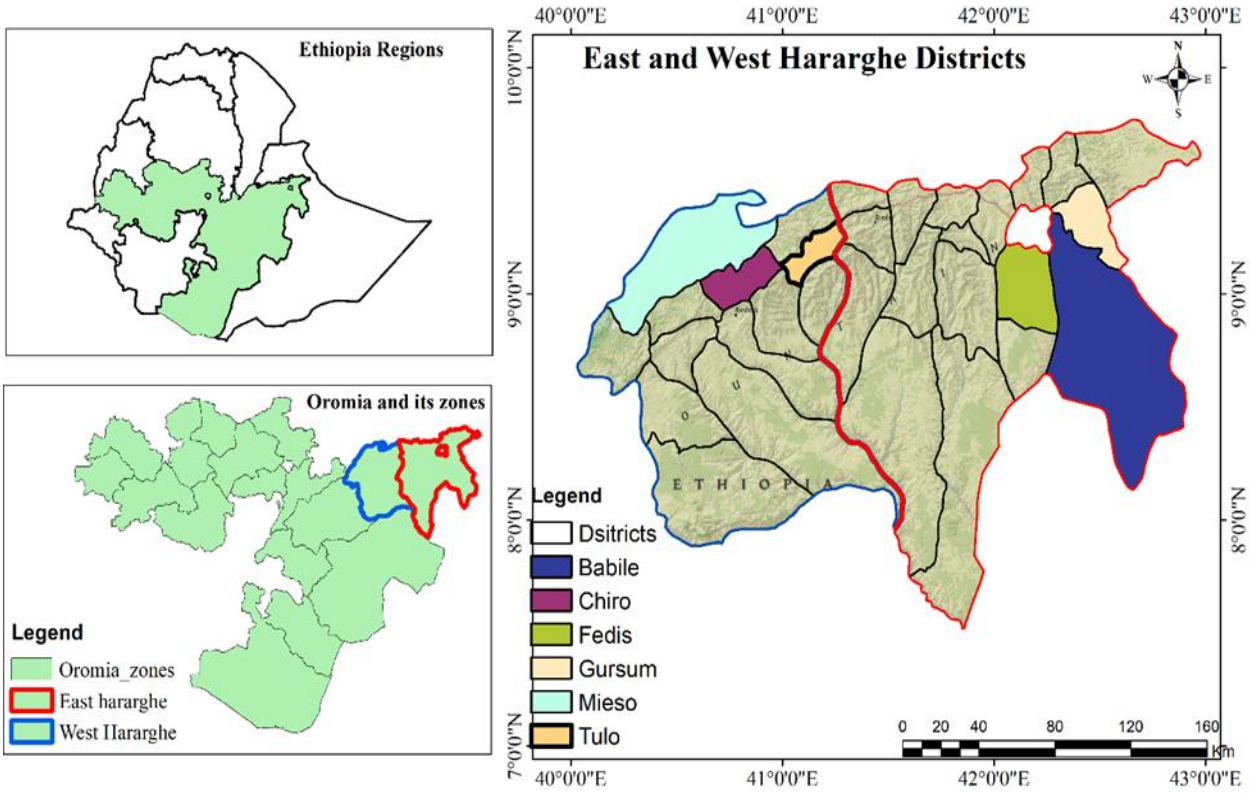


Figure 1. The study area Map

2.2. **Sampling Technique and Sample Size Determination**

A four-stage sampling design combining purposive and probability sampling techniques was deployed to ensure spatial representativeness, reflect agro-ecological variation, and minimize selection bias (Babbie, 2020). At the first stage, East Hararghe (for groundnut production) and West Hararghe (for soybean production) were purposively selected due to their established agro-ecological suitability and dominant share of regional commercial oilseed output (CSA, 2021). At the second stage, six primary production districts representing major commercial clusters were purposively selected: Babile, Fedis, and Gursum in East Hararghe, alongside Chiro, Tulo, and Mieso in West Hararghe (Creswell and Creswell, 2018). At the third stage, three principal oilseed-producing *kebeles* (the lowest administrative units in Ethiopia) were selected per district, establishing 18 sample *kebeles*. At the fourth stage, official *kebele* household rosters served as the primary sampling frame from which sample smallholder farmers were drawn using simple random sampling. The study's target population comprised all oilseed-producing smallholder households

across the six study districts. Baseline sample size determination was governed by the, Krejcie and Morgan (1970) formula.

$$n = \frac{X^2 NP(1-P)}{d^2(N-1)+X^2(P(1-P)} \quad (1)$$

$$ni = \frac{3.841 \times 123{,}230 \times 0.50(1-0.50)}{(0.05)^2 \times (123{,}230-1) \times 3.841 \times 0.5(1-0.50)} = 383$$

Where, n= sample size for each district; N= represents the target population of smallholder households in district , X^2 = the table value of chi-square for 1 degree of freedom at the confidence level of 95%, p = the population proportion (assumed to be 0 .50), d = the degree of accuracy expressed as a proportion (0.05).

To maintain balanced demographic representation across larger agricultural clusters, we allocated each district's sample size (n) across its three kebeles using Probability Proportional to Size (PPS) sampling based on updated rosters (Cochran, 1977; Lohr, 2021).

2.3.Types and Sources of Data

A cross-sectional survey design was used to capture household, farm, and institutional variables across Hararghe. Primary data were collected exclusively from smallholder oilseed producers between January and March 2026 via pre-tested, structured interviews. To cushion against non-response and data-cleaning attrition (De Brauw and Rozelle, 2008; Barrett *et al.,* 2020), 403 households were surveyed, exceeding the calculated minimum sample size (n = 383). The questionnaire covered demographics, socioeconomic traits, farm practices, market participation, and institutional access (extension, credit, market intelligence), supplemented by qualitative data for triangulation and empirical validation (Kassie *et al.,*2013;Legesse *et al.,* 2024). Secondary data were systematically compiled from annual performance reports, administrative records, and policy documents maintained by district agricultural offices, trade and market development agencies, and local input supplier networks.

2.4.Operational Definitions

Commercialization intensity

Smallholder commercialization intensity is operationalized as the proportion of gross physical oilseed output sold in output markets relative to the total physical oilseed harvest produced within a given production season (Govereh and Jayne, 2003; Strasberg et al., 1999; von Braun and Kennedy, 1994). In this study, commercialization intensity refers to the proportion of the total

value of production sold by smallholder households during 2025 the reference production period. It is measured using a crop-specific Household Commercialization Index (HCI), calculated as the ratio of the gross value of groundnut and soybean repectives sales to the total gross value of groundnut and soybean production, expressed as a proportion ranging from 0 to 1. The index is adapted from the crop commercialization measures used by Strasberg et al. (1999) and von Braun (1995). A value of zero indicates that no output from the selected oilseed crops was sold, whereas a value approaching one indicates that nearly all of the value of the selected crops produced was marketed. The resulting continuous measure captures variation in commercialization intensity across households and is used as the treatment variable in the Generalized Propensity Score analysis.

Multidimensional Food Security Outcomes

To capture the multidimensional nature of household food security spanning availability, access, utilization, and stability (CFS, 2009; FAO et al., 2013) this study operationalizes welfare outcomes through three validated metrics.

Household Dietary Diversity Score (HDDS): Measures nutrient adequacy and economic access by quantifying the consumption of 12 standard food categories over a 24-hour recall period (Swindale and Bilinsky, 2006; FAO, 2010). Higher values reflect superior micronutrient quality and purchasing capability.

Food Consumption Score (FCS): Captures food availability and caloric adequacy by combining the 7-day consumption frequency of eight food groups, weighted by nutrient density (WFP, 2008). FCS classifies household dietary quality into poor, borderline, or acceptable thresholds.

Reduced Coping Strategies Index (rCSI): Gauges household food stress, behavioral adjustments, and shock vulnerability by evaluating the frequency and severity of five standard negative coping mechanisms over a 7-day recall period (Maxwell and Caldwell, 2008; Maxwell et al., 2014). Higher scores denote acute food insecurity and diminished resilience.

2.5. Method of Data Analysis

Descriptive Analysis

Categorical and dummy variables were summarized using frequency and percentage distributions to map fundamental socioeconomic, demographic, and institutional landscapes; like gender of the household heads, educational, cooperative memberships, produced oilseeds types (Eastern for

groundnut vs. Western for soybean), and institutional parameters (credit, extension services, and market information). Continuous variables were evaluated using measures of central tendency and dispersion specifically reporting the mean, standard deviation, and range limits. This continuous metric framework was applied to quantify household family size, farming experience, geographic market distance, land allocation, and total production and marketing volumes (quantity produced versus quantity sold).

Model specifications

Smallholder commercialization is conventionally measured using the Household Commercialization Index (HCI), as the ratio of market sales to total agricultural output value (Strasberg et al., 1999; Govereh and Jayne, 2003).

$$\text{HCI} = \frac{\sum_{k=1}^{k} \bar{P}_k S_{ik}}{\sum_{k=i}^{k} \bar{P}_K Q_{ik}} \quad (2)$$

Where,

- HCI is household commercialization index, ($0 \leq \text{HCI} \leq 1$), where HCI = 0, represents complete subsistence production
- Sik *is the quantity of oilseeds output* k *that household* i *sold,*
- Pk *represents price of the oilseeds produced , and*
- Qik *represents the total quantity of output* k *that household* i *produced.*

While HCI provides a continuous spectrum of market engagement, methodological literature emphasizes two distinct analytical operationalization to capture market dynamics fully:

1. Continuous Variable : Maintained within the bounded [0, 1] continuum, continuous metrics are frequently subjected to square-root transformations $\sqrt{(HCIi)}$ to address structural right-skewness, mitigate heteroscedasticity, and eliminate random classification boundaries in fractional or Tobit specifications (Akaike, 1974; Wooldridge, 2010; Greene, 2018).
2. Discrete Structural Typologies: Stratifying continuous indices into sample-reflective ordinal quartiles such as subsistence, semi-commercialized, commercialized, and high-intensity commercial allows researchers to evaluate structural behavioral pathways and

non-linear transitions across developmental thresholds (von Braun and Kennedy, 1994; Carletto et al., 2011; Barrett et al., 2020).

Standard empirical studies often rely on Tobit or Fractional Response models for continuous, bounded commercialization indices (Tobin, 1958; Papke and Wooldridge, 1996). However, linear specifications cannot effectively isolate structural non-linearities and threshold-specific behavioral dynamics across discrete market pathways (Williams, 2016). When analyzing discrete commercialization tiers, standard ordered logit models are frequently applied.

These models strictly impose the parallel-lines (proportional odds) assumption, which posits that the parameter vector of explanatory variables (β) remains invariant across all ordinal thresholds (Greene, 2018; Wooldridge, 2010):

In smallholder agriculture, this assumption is regularly violated. Key institutional and structural covariates such as credit access, risk preferences, or transportation infrastructure exert differential impacts at low versus high thresholds of market participation (Long and Freese, 2014; Bojnec and Fertő, 2018). Forcing parameter equality across thresholds yields biased parameter estimates and misrepresents threshold-specific dynamics (Brant, 1990; Williams, 2006).

To resolve this specification restriction, literature increasingly favors the Generalized Ordered Logit framework (gologit2). This model relaxes the parallel-lines constraint by allowing parameter vectors (β) to vary across sequential cut-points (j = 1, 2, …..M-1) (Williams, 2006). To capture non-linear behavioral transitions along the market integration continuum, structural partitioning was applied to transform the continuous index into discrete behavioral typologies. The transformed index ($\sqrt{(HCIi)}$) was stratified into sample-reflective quartiles, yielding four balanced ordinal tiers (M = 4) (von Braun and Kennedy, 1994; Barrett et al., 2020):

1. Subsistence (Yi = 1)
2. Semi-commercialized (Yi = 2)
3. Commercialized (Yi = 3)
4. High-intensity commercial (Yi = 4)

While standard Tobit or Fractional Response models are conventionally applied to bounded continuous indices (Papke and Wooldridge, 1996), they fail to isolate threshold-specific dynamics across discrete commercialization pathways. Similarly, standard ordered logit models impose the parallel-lines (proportional odds) assumption, requiring parameter vectors (β) to remain invariant across all ordinal cut-points (Greene, 2018). Diagnostic testing via the Brant test confirmed that the parallel-lines assumption was violated for several key covariates ($p < 0.05$), indicating that key factors (e.g., credit access, market distance) exert differential impacts at distinct stages of commercialization (Brant, 1990). To address this, we apply a Generalized Ordered Logit model (gologit2), which relaxes the parallel-lines restriction by allowing parameter vectors (βj) to vary across sequential cut-points (j = 1, 2, ….., M- 1) (Williams, 2006, 2016): The model is specified as follows:

$$P(Yi > j|Xi) = g(X\,i\ \beta\,j\ ) = \frac{exp(\alpha j\ + Xi\,\beta j\ )}{1+exp(\alpha j\ + X\,i\,\beta\,j\ )} \quad \text{for } j = ,1,2,3 \tag{3}$$

Where:

- Y_i is the observed ordinal commercialization category ($Y \in \{1, 2, 3, 4\}$) derived from the square-root transformed Household Commercialization Index ($\sqrt{(HCIi)}$) for household *i*.
- X_i represents the vector of independent explanatory variables (socioeconomic asset endowments, demographic profiles, and institutional access parameters).
- α_j represents the category-specific intercept (cut-point) for threshold *j*.
- β_j represents the vector of regression coefficients unique to each threshold *j*.

For our four-tier commercialization typology (M = 4), the model deconstructs the analysis by simultaneously estimating three sequential, localized operational logit thresholds (j = 1, 2, 3):

- Threshold 1 (j = 1): P (Yi > 1) = Subsistence (Y = 1) vs. Higher Tiers ($Y \in \{2, 3, 4\}$),
- Threshold 2 (j = 2): P (Yi > 2) = Subsistence and Semi-commercialized ($Y \leq 2$) vs. Higher Tiers ($Y \in \{3, 4\}$),
- Threshold 3 (j = 3): P(Yi > 3) = Lower Tiers ($Y \leq 3$) vs. High-Intensity Commercial (Y = 4).

Because the raw coefficients (β_j) from logit models express changes in log-odds and are difficult to interpret directly, post-estimation.

By allowing covariates to take unconstrained values across cut-points, this framework uncovers whether specific structural barriers selectively hinder entry into initial market participation (Y > 1) or prevent fully commercialized farmers from scaling up to high-intensity market integration (Y > 3) (Bojnec and Fertő, 2018; Tabe-Ojong and Geffersa, 2024).

Because raw coefficients (β_j) express changes in log-odds, post-estimation Average Marginal Effects (AME) were calculated to capture direct changes in probability across each commercialization tier. Average Marginal Effects (AME, dy/dx) were computed. The AME isolates the specific partial changes in the probability of a household occupying a given commercialization tier per unit change in the explanatory variable, written as: $AME =$

$$\frac{\partial P(Y_i = m \backslash x)}{\partial X_{ki}} \tag{4}$$

Where; *m* denotes the specific commercialization tier (1, 2, 3, or 4), focusing specifically on the structural drivers of households attaining the terminal phase of market integration (High-Intensity Commercial).

Because commercialization intensity spans multi-tier operational levels, standard binary treatment evaluation frameworks such as conventional Propensity Score Matching (PSM) fail to capture treatment effect heterogeneity across varying dosage tiers (Imbens, 2000; Cattaneo, 2010). Binary categorizations obscure non-linear impact trajectories, multi-group confounding, and dosage-response dynamics.

To overcome these limitations and estimate causal effects across continuous treatment regimes, Hirano and Imbens (2004) developed the Generalized Propensity Score (GPS) framework. The (GPS) acts as a continuous balancing metric that adjusts for multi-group covariate confounding across all strata of treatment intensity (Bia and Mattei, 2012; Kluve et al., 2012).

Thus, to evaluate the impact of continuous treatment intensity (Ti = HCIi Ɛ [0, 1]), on food security outcomes (Oi) without imposing artificial categorization, we employ the Generalized Propensity Score (GPS) framework (Hirano and Imbens, 2004).

Step 1: Conditional Treatment Model

The conditional distribution of treatment Ti given covariates Xi is estimated using a Fractional Logit / Generalized Linear Model (GLM) to account for the [0, 1] boundaries:

$$R_i = r(T_i, X_i) = f_{T/X}(T_i / Xi) \quad (5)$$

Where

R_i =Generalized Propensity Score (GPS) for household i. It is a single a probability value assigned to that specific household.

$r(T_i, X_i)$= A mathematical function showing that the score is calculated by matching the specific continuous treatment level (T_i) with that household's baseline characteristics (Xi).

Under the weak un-confoundedness assumption, conditioning on the estimated score Ri eliminates observable selection bias (Guardabascio and Ventura, 2014).

Step 2: Outcome Equation and Dose-Response Function

After verifying covariate balance across propensity score strata, the conditional expectation of the outcome Oi is modeled as a function of treatment level t and score r:

$$E[Oi \mid T i = t, \; R_i = r] = \gamma(t, r) \quad (6)$$

The unbiased Average Dose-Response Function (DRF, θ(t)) across the continuous treatment spectrum is calculated as:

$$\theta(t) = E[\gamma(t, r(t, Xi))] \quad (7)$$

Where θ stands for the DRF and t for the treatment level. DRF shows the connection between the intensity of commercialization and the post-treatment results. Where i, is sample of households

(1… 383), Xi is pre-treatment variables, Ti is the actual level of treatment and $Oi = Oi\ (Ti)$ is a set of outcome variables associated with the treatment level. Mapping θ(t) allows us to detect potential non-linearities, threshold effects, and diminishing returns of commercialization on multidimensional food security outcomes (Tabe-Ojong and Geffersa, 2024). .

To measure discrete impact shifts across the constructed commercialization tiers, we specify a multi-valued Inverse-Probability Weighted Regression Adjustment (IPWRA) estimator. The IPWRA estimator possesses a double-robust property, yielding consistent parameters if either the treatment assignment model or the outcome model is correctly specified (Wooldridge, 2010).

Under the Conditional Independence Assumption (CIA), the Average Treatment Effect on the Treated (ATET}, τ) relative to the subsistence baseline (C = 0) is estimated as:

$$\tau = E\ [\ (O_i(c)\ |C_i = c)\ ] - [\ E\ (O_0|C_i = c)\ ] \quad (8)$$

Where τ is the Average Treatment effect on the Treated households (ATET), C represents the multi-valued treatment indicator (C=0 for subsistence reference, up to C=3 for high-intensity commercial). Ci Ɛ {0, 1, 2, 3} represents the multi-valued commercialization treatment tier. conditional expectation of the food security outcome (Oi).

Table 1. Variables, operational definitions, measurements, and hypothesized directional signs

Variable Label	Operational Description	Expected Sign on HCI
Gender (1 = Male)	Gender imbalances in resource control and value-addition division of labor	+/-
Education Level(1=Formal)	Human capital factor enhancing price margin assessment and strategic bargaining power	+
Cooperative Member(1=yes)	Institutional link providing collective marketing channels and input channels	+
Market Information(1=yes)	Access to symmetric, real-time pricing reducing transaction search costs	+
Access to Credit(1= yes)	Financial relaxation to invest in higher-yielding inputs , fertilizers, and technology	+
Extension Services(1=yes)	Farmers with consistent access to extension services often achieve significantly higher crop yields and better household incomes	+
Oilseed Experience Continuous (Years in oilseed farming)	Specialized knowledge accumulation and relational networking/ It enables to blend traditional knowledge with modern agronomic practices	+
Family Size (Number of household members)	Proxy indicator representing internal farm household labor availability	+ / -
Distance to Market (Distance in Kilometers)	Physical transaction friction cost and physical logistics isolation proxy	-
Land Allocated (Hectares cropped with oilseeds)	Productive asset allotment mapping localized specialization thresholds	+
Quantity Produced (Gross volume harvested in Kg)	Direct structural indicator of household expansion beyond absolute subsistence	+

Sources: own constructions from literature review

3. Empirical Results and Discussion

Demographic, Socioeconomic, and Institutional Characteristics

The cross-sectional data collected from 383 smallholder edible oilseed farmers across six selected districts in East and West Hararghe were analyzed using descriptive statistics. The demographic, socioeconomic, and institutional profile of the sampled households categorized by categorical, continuous variables and distribution of smallholder by commercialization status/tier summarized in tables 2, 3, and 4 consecutively.

Table 2. Demographic, socio-economic, and institutional characteristics (Dummy Variables)

Variables		Frequency	Percent
Sex of household head	Female	101	26.37
	Male	282	73.63
Education level	Formal	199	51.96
	No-formal	184	48.04
Cooperative membership	None	218	56.92
	Member	165	43.08
Market information	No access	105	27.42
	Access	278	72.58
Access to credit	No access	286	74.67
	Access	97	25.33
Access to extension services	No access	107	27.94
	Access	276	72.06
Edible oilseeds type	Groundnuts	204	53.26
	Soybean	179	46.74

Source: Field Survey Data (2026).

As detailed in Table 1, male-headed households dominate the sample (73.63%), while female-headed households account for 26.37%. This gender distribution underscores the prevailing patriarchy in rural agricultural production systems, where men predominantly retain control over productive farm assets, land allocation, and market engagement a finding consistent with previous empirical literature on smallholder commercialization in East Africa (Mohammed et al., 2019). Regarding human capital, 51.96% of household heads possessed formal education, whereas 48.04% lacked formal schooling. Educational attainment plays a pivotal role in market integration; educated managers are better positioned to process market signals, navigate complex value chains, and evaluate the economic trade-offs of adopting modern technologies. Conversely, farmers without formal education face higher cognitive entry barriers regarding extension materials and institutional value-chain interventions.

Institutional engagement revealed mixed dynamics. Membership in agricultural cooperatives stood at 43.08%, leaving 56.92% of smallholders unorganized. This highlights a structural deficit, as non-members are deprived of economies of scale, collective bargaining power, reduced transaction costs, and streamlined access to subsidized inputs. In contrast, access to market information was relatively high (72.58%), serving as a crucial catalyst for mitigating information asymmetry and improving price discovery at the farm-gate.

However, formal credit access remains a severe binding constraint: approximately 74.67% of smallholders lacked access to credit facilities, limiting their capacity to finance modern inputs, post-harvest logistics, or productivity-enhancing equipment. On the other hand, 72.06% of respondents reported active contact with agricultural extension services, providing a viable institutional channel for disseminating agronomic best practices and market-oriented innovations. Enterprise distribution showed that 53.26% engaged in groundnut production (concentrated in East Hararghe) and 46.74% cultivated soybeans (West Hararghe).

Table 3. socio-economic, demographic and institutional (continues variables)

Variable	Obs	Mean	Std. dev.	Min	Max
Oilseeds productions experience	383	19.044	10.677	5	44
Family size	383	7.402	1.741	3	12
Distance from the main market (Km)	383	15.005	5.869	3	35
Land allocated to edible oil seeds	383	.642	.412	.15	2
Quantity produced in kilogram	383	679.707	313.520	150	1780
Quantity (edible oil seeds) sold(Kg)	383	571.279	281.474	0	1600

Source: Field Survey Data (2026).

The continuous variable profiles (Table 3) further elucidate smallholder operational capacities. Households exhibited substantial agricultural experience in oilseed cultivation, averaging 19.04 years (SD = 10.68). This extensive background suggests a deep familiarity with localized production risks, though long-held conventional habits may also induce status-quo bias against novel agronomic packages. The mean household size was 7.40 members (SD = 1.74), reflecting the dual role of large rural families as both a source of family labor for labor-intensive farm tasks and a driver of high home-consumption demand.

Spatial accessibility remains an impediment, with households located an average of 15.01 km (SD} = 5.87) from the nearest primary market center. Proximity to market infrastructure directly governs transport overheads and perishable handling risks. Land allocation to edible oilseeds averaged 0.64

hectares (SD = 0.41), spanning a range of 0.15 to 2.00 hectares. Although national trends indicate a gradual expansion of land dedicated to oilseeds over the past decade and a half (CSA, 2020), absolute holding sizes in the study area remain fundamentally constrained by land fragmentation. In terms of yield and output, smallholders produced an average of 679.71 kg (SD = 313.52) of oilseeds per production cycle, of which an average of 571.28 kg (SD = 281.47) was marketed, indicating a high gross output-to-marketed ratio among active producers.

Table 4: Distribution of smallholder by commercialization status/tier

Commercialization Level (tier)	Frequency (N)	Proportion (%)
Subsistence	115	30.0%
Semi-commercialized	87	22.72%
Commercialized	96	25.07%
High Intensity Commercial	85	22.19%
Total Sample	383	100.0%

Source: Own computation of Data (2026)

The empirical breakdown in Table 4 illustrates a wide gradient of market participation across the sample. Subsistence-oriented households (Tier 1) constitute the single largest individual segment, accounting for 30.03% (n = 115) of the population. This highlights that a substantial portion of smallholders continue to prioritize risk-averse, food-self-sufficiency strategies, directing the bulk of their harvest toward domestic consumption rather than market demand.

Conversely, the intermediate groups semi-commercialized (22.72%) and commercialized (25.07%) households collectively comprise nearly half (47.79%) of the total sample. This significant middle cohort reflects a fluid transition zone wherein producers strategically respond to market price signals while retaining partial consumption safeguards. Finally, the high-intensity commercial group (Tier 4) accounts for 22.19% (n = 85) of the sample. These specialized smallholders operate predominantly as market-driven enterprises; they capitalize on price incentives, utilize modern inputs more intensively, and maintain strong linkages with commercial value chain actors.

Determinants across Commercialization Tiers

Global diagnostic tests confirm that the specified empirical model exhibits high explanatory power and structural stability. The overall Wald Chi-Square test (Wald X^2 (33) = 148.54, $p < 0.0001$) is statistically significant at the 1% level, confirming that the combined explanatory variables jointly exert a non-zero influence on smallholder commercialization pathways. The Pseudo-R^2 value of 0.2580 indicates that approximately 25.8% of the total cross-sectional variation in smallholder market participation intensity across East and West Hararghe is directly explained by the model's socioeconomic, demographic, and institutional covariates.

Table 5: Threshold Parameter Estimates (gologit2)

Variable / Category	Threshold 1: Subsistence vs. Higher	Threshold 2: Semi-Comm. vs. Higher	Threshold 3: Comm. vs. High-Intensity
Gender (Male = 1)	-0.9103*** (0.3243)	-0.0058 (0.2676)	0.5584 (0.3778)
Experience (Years)	0.0438** (0.0194)	-0.0048 (0.0187)	0.0061 (0.0236)
Education (Formal = 1)	1.6188*** (0.3472)	-1.0786*** (0.3383)	-1.0592*** (0.3934)
Oilseed Type (Groundnut = 1)	-0.2441 (0.4095)	1.0247** (0.4329)	1.3174** (0.5808)
Distance to Market (Km)	-0.0648** (0.0278)	0.0434 (0.0294)	0.0286 (0.0386)
Extension Access (Yes = 1)	-0.8654** (0.4024)	-0.2094 (0.3832)	1.2492** (0.5863)
Credit Access (Yes = 1)	-0.1595 (0.3458)	-0.4603 (0.3203)	-0.6945 (0.4307)
Market Info Access (Yes = 1)	0.4846 (0.3202)	-0.5423 (0.3637)	0.0655 (0.5287)
Family Size (Members)	-0.0755 (0.0814)	-0.0332 (0.0828)	0.0171 (0.1025)
Cooperative Member (Yes = 1)	-0.2911 (0.2687)	0.4341* (0.2545)	-0.1409 (0.3274)
Quantity Produced (Kg)	0.0008 (0.0006)	0.0037*** (0.0007)	0.0046*** (0.0006)
Constant (_cons)	1.2890 (1.0495)	-2.4130** (1.2164)	-6.8128*** (1.6895)
Number of Observations (N) = 383, Wald Chi-Square (Wald χ^2 (33))= 148.54, Prob > Chi-Square (p-value)=0.0000***,Pseudo R-Squared (Pseudo R^2)=0.2580			

*Standard errors in parentheses. Significance levels: * p < 0.10, ** p < 0.05, *** p < 0.01. Number of observations (N) = 383.*

Table 6: Average Marginal Effects for High-Intensity Commercialization

Explanatory Variable (dy/dx)	Marginal Effect	Std. Err.	z-stat	p-value
Gender (Male Headed vs. Female)	0.0605	0.0390	1.55	0.121
Oilseed Production Experience	0.0007	0.0026	0.26	0.796
Education Level (formal education vs. None)	-0.1252	0.0479	-2.61	**0.009*** **
Oilseed Type (Groundnut vs. Soybean)	0.1455	0.0638	2.28	**0.023** **
Distance from Main Market	0.0032	0.0042	0.75	0.451
Access to Extension Services (Yes)	0.1369	0.0629	2.18	**0.030** **
Access to Credit (Yes)	-0.0736	0.0447	-1.65	**0.100***
Access to Market Information (Yes)	0.0072	0.0580	0.12	0.901
Family Size	0.0019	0.0113	0.17	0.867
Cooperative Membership (Yes)	-0.0155	0.0360	-0.43	0.667
Quantity Produced in kg	0.0005	0.0000	12.86	**0.000*** **

Source: Own Survey Data computation (2026) *Significance levels: * p < 0.10, ** p < 0.05, *** p < 0.01.*

Output Scale as the Primary Engine of Scale Economies

The physical volume of oilseeds produced emerged as a highly significant driver of market integration across advanced commercialization thresholds. Quantity produced was statistically significant at the 1% level in both Threshold 2 (β= 0.0037, p < 0.001) and Threshold 3 (β = 0.0046, p < 0.001), as well as within the post-estimation Average Marginal Effects (Table 6). Holding all other variables constant, every additional 100 kg of oilseeds produced increases the probability of a household reaching high-intensity commercialization (Tier 4) by 5.0 percentage points (AME = 0.0005, p < 0.001). This result provides robust empirical confirmation of the theoretical mechanisms governing threshold effects and fixed transaction costs in smallholder agriculture (Barrett, 2008). In rural production environments like Hararghe, smallholders face substantial invariant transaction costs, including price search, negotiation, and bulk transport logistics. Because fixed overheads are invariant to transaction volume, smallholders must achieve a critical output volume before commercial market entry becomes economically viable (Barrett, 2008; Duffy, 2009). Sub-threshold producers are unable to dilute unit transaction costs, forcing them to remain reliant on local spot transactions or subsistence cycles. These findings directly align with empirical evidence from Ethiopian agricultural marketing, where expanding production output

acts as the principal prerequisite for generating the marketable surplus needed to escape low-equilibrium subsistence traps (Hegena and Teshome, 2022).

Enterprise Choice and Value Chain Asymmetries: Groundnut vs. Soybean

Crop productions selection demonstrated a pronounced structural divergence in market participation intensity. Smallholders cultivating groundnuts as their primary oilseed exhibited a 14.55 percentage point higher probability of operating in the high-intensity commercial tier (AME = 0.1455, p = 0.023) compared to soybean producers. Enterprise choice was significant across Threshold 2 (β= 1.0247, p = 0.018) and Threshold 3 (β= 1.3174, p = 0.023). This disparity highlights deep structural differences between regional oilseed value chains in Eastern Ethiopia. Groundnut production, concentrated predominantly in East Hararghe, benefits from a mature, decentralized, and competitive market environment characterized by multiple private market channels, including rural traders, urban wholesalers, and cottage oil processors (Gelana, 2020; Toficka and Iggeba, 2025). This diversity of market outlets lowers entry barriers and enhances farm-gate price realization. Conversely, soybean production in West Hararghe operates within a relatively thin, underdeveloped, and centralized value chain (IISTE/EIAR, 2023; Wubetu, 2020). Smallholder soybean growers face limited local demand, highly concentrated buyer networks (primarily institutional aggregators and cooperative unions), and restrictive price-setting mechanisms, suppressing incentives for intensive market integration.

Structural Evolution of Agricultural Extension Services

Access to agricultural extension services functioned as a powerful catalyst for high-tier commercialization, raising the likelihood of entering the high-intensity commercial tier by 13.69 percentage points (AME = 0.1369, p = 0.030). However, the threshold-deconstructed parameter estimates reveal a critical non-linear trend: extension contact yielded a negative coefficient at Threshold 1 (β= -0.8654, p = 0.032), but reversed to a strongly positive coefficient at Threshold 3 (β= 1.2492, p = 0.033). This structural shift reflects a realignment of advisory mandates across commercialization tiers. For resource-constrained subsistence households (Tier 1), public extension services in rural Ethiopia prioritize food security, crop production risk mitigation, and basic agronomic interventions (Berhanu *et al.,* 2014; Gebremedhin *et al.,* 2009). At this baseline stage, extension advisory services direct output toward home consumption and risk containment

rather than immediate market supply. However, once smallholders cross basic subsistence thresholds and achieve surplus output, development agents shift advisory support toward market orientation, quality standardization, post-harvest handling, and buyer linkage coordination (Abafita *et al.,* 2016; Getahun, 2020; Matita *et al.,* 2022). This structural reorientation drastically reduces transaction costs, enabling commercialized producers to transition into high-intensity market tiers.

Human Capital Reallocation and the Formal Education Paradox

The formal education revealed a compelling behavioral trade-off across commercialization tiers. Having a formally educated household head was highly significant ($p < 0.01$) across all model specifications, but displayed a directionally inverted relationship as households advanced through commercialization thresholds. At Threshold 1, primary education strongly promoted transition out of absolute subsistence *(*β= 1.6188, $p < 0.001$). However, at advanced stages (Thresholds 2 and 3), formal education exerted a statistically significant negative effect on higher-tier market integration (β= -1.0786, $p = 0.001$ and β = -1.0592, $p = 0.007$, respectively), resulting in a negative marginal effect for Tier 4 (AME= -0.1252, $p = 0.009$). This empirical outcome reflects a well-documented human capital and off-farm labor reallocation mechanism in rural Ethiopia (Barrett *et a*l., 2001; Bezu *et al.,* 2012). While baseline literacy and numeracy lower cognitive barriers to processing market information and adopting input technologies at entry level (Gebremedhin and Jaleta, 2012), higher educational attainment simultaneously reduces search costs in off-farm labor markets. In climate-vulnerable agricultural environments like Hararghe, educated household heads mitigate agricultural production risks by reallocating labor and capital away from intensive, climate-exposed farm production toward off-farm micro-enterprises, grain trading, and rural wage employment (Eneyew and Bekele, 2012; Oseni and Winters, 2014). Educated smallholders opt to maintain semi-commercialized farming operations while channeling financial and human capital into off-farm portfolios, leading to lower commercial intensity in agricultural value chains.

Credit Constraints and Liquidity-Smoothing Mechanisms

Formal credit access exhibited a marginally significant negative relationship with high-intensity commercialization (AME = -0.0736, p = 0.100). This result, counterintuitive to classical production theory, is rooted in the structural dynamics of rural financial markets and credit fungibility in Ethiopia. When formal agricultural credit packages are small in volume, short-term in duration, and disbursed under rigid repayment schedules, they are ill-suited to finance medium-term structural capital investments (Karlan *et al.,* 2014; Komicha and Öhlmer, 2006). In low-income agrarian systems subject to seasonal cash flow shocks, smallholders face severe pre-harvest liquidity constraints during the *kiremt(summer season)* lean period (Workneh *et al.,* 2020). Due to the liquidity of cash loans, resource-poor farmers divert short-term microcredit away from modern agricultural input packages toward emergency household consumption, student schooling ,medical costs, and food security buffers (Ali and Deininger, 2014; Diagne and Zeller, 2001). Rather than serving as investment capital to expand to commercial scale, formal credit functions as a risk coping and survival mechanism, failing to drive households into high-intensity market-integration tiers.

Geographic Remoteness and Gender Disadvantages at Entry

Spatial remoteness and household headship operated primarily as entry-level structural barriers rather than drivers of advanced commercial intensity. Physical distance to the nearest primary market center significantly increased the likelihood of remaining trapped in subsistence at Threshold 1 (β = -0.0648, p = 0.020), driven by elevated unit transport costs and information asymmetry (Mamo *et al.,* 2014). Similarly, female-headed households faced a pronounced disadvantage at initial market entry (β= -0.9103, p = 0.005), reflecting structural inequalities in land access, family labor availability, credit access, and market negotiation power (Mulema *et al*., 2021; Tiruneh *et al.,* 2001). However, at higher commercialization tiers (Thresholds 2 and 3), neither market distance nor gender headship remained statistically significant. This indicates that once smallholders overcome initial entry barriers often through cooperative aggregation, cluster sales, or enterprise specialization physical output volume and crop enterprise choice supersede geographic distance and headship gender as the primary drivers of commercial success (Gebremedhin and Jaleta, 2012; Tavenner and Crane, 2018).

Causal Impacts of Commercialization on Household Food Security

To evaluate the causal effects of edible oilseed commercialization intensity on multidimensional smallholder welfare while controlling for observable selection bias and non-linearities, multivalued treatment effect models were estimated using Inverse Probability Weighted Regression Adjustment (IPWRA). Outcome metrics capture three distinct dimensions of food security: the Food Consumption Score (FCS) measuring caloric frequency and basic diet quality; the Household Dietary Diversity Score (HDDS) measuring nutrient adequacy across food groups; and the Reduced Coping Strategies Index (rCSI) measuring short-term behavioral vulnerability to food stress. Table 7 presents the double-robust Average Treatment Effects (ATE) across commercialization tiers, evaluated against the reference baseline of pure subsistence households (Tier 1).

Table 7: IPWRA Treatment Effect Estimates across Food Security Metrics

Outcome Variable and Treatment Contrast	Coefficient (ATE)	Robust Std. Err.	z-stat	p-value	[95% Confidence Interval]
Food Consumption Score (FCS)					
Semi-commercialized vs. Subsistence	0.0802	0.0289	2.77	0.006***	[0.0234, 0.1370]
Commercialized vs. Subsistence	-0.0378	0.0518	-0.73	0.465	[-0.1393, 0.0636]
High-intensity Commercial vs. Subsistence	0.0383	0.0368	1.04	0.299	[-0.0339, 0.1105]
Potential Outcome Mean (μ_0): Subsistence	2.9037	0.0250	116.05	0.000***	[2.8547, 2.9527]
Household Dietary Diversity Score (HDDS)					
Semi-commercialized vs. Subsistence	0.0316	0.0799	0.40	0.693	[-0.1250, 0.1882]
Commercialized vs. Subsistence	0.0451	0.0549	0.82	0.411	[-0.0625, 0.1527]
High-intensity Commercial vs. Subsistence	0.0175	0.0413	0.42	0.671	[-0.0634, 0.0985]
Potential Outcome Mean (μ_0): Subsistence	2.5148	0.0357	70.43	0.000***	[2.4449, 2.5848]
Reduced Coping Strategies Index (rCSI)					

Semi-commercialized vs. Subsistence	-0.0266	0.0946	-0.28	0.778	[-0.2121, 0.1588]
Commercialized vs. Subsistence	-0.0459	0.0738	-0.62	0.534	[-0.1906, 0.0987]
High-intensity Commercial vs. Subsistence	-0.0866	0.0777	-1.11	0.265	[-0.2389, 0.0657]
Potential Outcome Mean (μ_0): Subsistence	2.7459	0.0486	56.54	0.000***	[2.6507, 2.8411]

*Source: Own Survey Data computation (2026) , Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.10.*

Early-Stage Non-Linearity: Commercialization Thresholds and Caloric Security

The empirical results demonstrate a highly localized, non-linear causal impact of market integration on household caloric frequency. Transitioning from pure subsistence (Tier 1) to semi-commercialized status (Tier 2) generates a statistically significant positive treatment effect on the Food Consumption Score (ATE = 0.0802, z = 2.77, p = 0.006). Evaluated against the baseline Potential Outcome Mean (μ_0 = 2.9037) for subsistence smallholders, this early market transition yields a 2.76% relative improvement in food consumption frequency and staple stability. However, as smallholders advance into fully commercialized (Tier 3: ATE = -0.0378, p = 0.465) and high-intensity commercial tiers (Tier 4: ATE = 0.0383, p = 0.299), the causal treatment effects become statistically indistinguishable from zero.

This pattern reveals a critical nutritional threshold effect in agricultural commercialization. In low-income agrarian contexts like Hararghe, early market entry relaxes severe liquidity constraints, providing immediate cash income that exhibits a high marginal propensity to spend on baseline food items and staple caloric preferences (Chege *et al.*, 2018; Ogutu and Qaim, 2019; Radchenko and Corral, 2018). Once immediate caloric deficits are resolved and baseline consumption security is achieved, the income elasticity of food consumption declines (Ntakyo and van den Berg, 2019). Additional cash windfalls from higher commercialization tiers are systematically reallocated toward productive farm inputs, asset accumulation, debt servicing, or non-food consumption (Ecker *et al.,* 2023; Mulenga *et al.,* 2021; Workneh *et al.,* 2021). Robustness checks using a binary treatment specification (teffects ipw) confirmed this directional pattern, though collapsing the continuous FCS metric into binary thresholds reduced statistical precision (ATE = 0.0436, p = 0.137), underscoring the methodological importance of utilizing continuous variance in dietary recall data to detect subtle shifts in consumption frequency (Ecker *et al*., 2023).

The Cash-Crop Income Paradox and Local Food Market Deficits

In stark contrast to caloric frequency outcomes, oilseed commercialization produces no statistically significant causal improvement in the Household Dietary Diversity Score (HDDS) across any commercialization contrast (ATE = 0.0316, p = 0.693 for Tier 2; ATE= 0.0451, p = 0.411 for Tier 3; ATE = 0.0175, p = 0.671 for Tier 4). Evaluated against a baseline subsistence dietary mean of μ_0= 2.5148, commercial smallholders fail to translate higher cash revenues from groundnut and soybean sales into more diverse dietary outcomes at home.

This decoupling illustrates a classic Cash-Crop Income Paradox driven by two structural mechanisms operating in rural Ethiopia:

1. **Thin and Isolated Rural Retail Markets:** In semi-arid regions like Hararghe, local food environments suffer from severe structural thinness, physical isolation, and seasonal supply deficits). When regional markets lack continuous supplies of nutrient-dense food groups such as fresh fruits, vegetables, animal-source proteins, and dairy increased cash liquidity cannot overcome physical supply deficits (Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2018; Hirvonen *et al.,* 2021).
2. **Crop Displacement and Monoculture Risks:** Expanding oilseed production requires reallocating land and family labor away from diverse food plots (e.g., home gardens, intercropped legumes, traditional food crops) toward specialized monoculture fields (Passarelli *et al.,* 2018). As farm households transition from self-sufficient producers of varied foodstuffs to market-dependent food buyers, they become exposed to local retail price volatility and a narrow spectrum of market-available food choices (Carletto *et al.,* 2017; Mulenga *et al.,* 2021). Consequently, specialized commercial farming reduces on-farm production diversity without providing accessible market-based dietary diversity in return (Passarelli *et al.,* 2018).

Consumption Smoothing and Shock Resilience Ecosystems

The causal estimates for the Reduced Coping Strategies Index (rCSI) display a protective, negative point-estimate pathways across advancing commercialization brackets (ATE = -0.0266, p = 0.778 for Tier 2; ATE = -0.0459, p = 0.534 for Tier 3; ATE = -0.0866, p = 0.265 for Tier 4). Evaluated against the baseline subsistence coping stress mean (μ_0= 2.7459), high-intensity commercial smallholders experience an 8.66% relative reduction in severe food stress coping behaviors.

While this negative pathways indicates that commercial revenues assist in buffering seasonal cash deficits (Amare *et al.,* 2021; Janzen and Carter, 2019), the lack of statistical significance (p > 0.05) highlights the complex risk environment of rural Ethiopia. In ecologically fragile contexts like Hararghe, commercial market revenues alone are insufficient to neutralize systemic shocks, such as recurrent droughts, crop pest infestations, and localized food inflation (Becquey *et al.,* 2023; Hirvonen *et al.,* 2020). Furthermore, exogenous safety nets most notably public transfers through the Productive Safety Net Programme (PSNP) and informal community risk-sharing networks (Abay *et al.,* 2022; Berhane *et al.,* 2017) heavily mediate household coping dynamics. Because subsistence and commercialized households simultaneously rely on these broader institutional buffers to absorb severe climate and economic shocks, the isolated marginal contribution of cash crop sales on coping stress is diluted (Abay *et al*., 2022; Welch *et al.,* 2021).

Conclusions, Policy Implications, and Future Research Directions

Conclusions

This study provides a comprehensive empirical analysis of the socio-economic, demographic, and institutional determinants driving smallholder market integration pathways among oilseed (groundnut and soybean) producers in the East and West Hararghe zones of Oromia Regional State, Ethiopia, and evaluates its causal welfare impacts on household food security. By integrating a Generalized Ordered Logit (gologit2) framework with double-robust Inverse Probability Weighted Regression Adjustment (IPWRA) estimators across three standardized food security dimensions (Food Consumption Score [FCS], Household Dietary Diversity Score [HDDS], and Reduced Coping Strategies Index [rCSI]), the analysis isolates the non-linear, threshold-dependent mechanisms governing smallholder transition from pure autarky to high-intensity commercialization.

The empirical findings confirm that smallholder agricultural commercialization is neither a uniform nor a linear continuum. Rather, it is characterized by prominent institutional entry thresholds, structural value chain asymmetries, and a pronounced causal welfare plateau:

1. **Threshold-Dependent Entry Barriers:** Physical market remoteness and gender headship operate as severe entry-level penalties that trap female-headed and geographically isolated households in absolute subsistence. However, once smallholders cross the baseline entry threshold, these demographic and spatial barriers cease to be statistically significant. Beyond entry, physical output scale and value-chain configuration become the absolute drivers of commercial intensity.
2. **Scale Economies and Value Chain Asymmetries:** Total physical output produced serves as the primary engine of market integration, confirming that local producers face substantial fixed transaction costs that require a critical physical volume to dilute. Furthermore, market integration pathways diverge significantly across crop varieties: groundnut producers in East Hararghe benefit from a mature, decentralized, and competitive market network, whereas soybean producers in West Hararghe remain constrained by thin, highly centralized, and monopsonistic market structures.
3. **Institutional Divergence and the Formal Education Paradox:** Public extension services exhibit a non-linear trajectory, initially prioritizing food self-sufficiency at baseline levels before pivoting toward market linkages, quality standards, and post-harvest management at higher tiers. Conversely, formal rural credit fails to drive commercial expansion because small-volume, short-term loans function primarily as liquidity-smoothing survival buffers during the *kiremt* /*summar season*/lean season. Crucially, formal education exhibits a behavioral trade-off: basic literacy enables initial transition out of subsistence, but educated household heads actively reallocate human capital away from intensive, climate-vulnerable agricultural production toward off-farm micro-enterprises and wage employment.
4. **The Causal Welfare Plateau and the "Cash-Crop Income Paradox":** Causal treatment effect estimates reveal a pronounced non-linear welfare response. Transitioning from pure subsistence to semi-commercialized status yields an immediate, statistically significant improvement in caloric frequency and staple stability (ATE = 0.0802, $p = 0.006$). However, this welfare dividend plateaus at higher commercialization tiers, showing non-significant

impacts on Household Dietary Diversity (ATE = 0.0175, p = 0.671) and behavioral shock resilience (ATE = -0.0866, p = 0.265). Cash windfalls generated from intensive commercialization are systematically reallocated toward productive farm inputs, asset accumulation, and non-food expenditures rather than diverse foods a dynamic exacerbated by on-farm monoculture displacement and thin local retail food markets.

Policy Implications and Targeted Recommendations

Based on these empirical insights, a multi-tiered, stage-specific policy framework is required to reconcile smallholder commercialization with inclusive economic growth and smallholder food security in Eastern Ethiopia:

1. Scale-Up Production Output via Village Aggregation Infrastructure

Given that total harvest volume is the primary driver for overcoming fixed transaction costs, regional agricultural offices should prioritize productivity-enhancing packages (high-yielding, drought-tolerant seed varieties and modern agronomic practices). To assist sub-threshold smallholders in reaching marketable volumes, public policy must invest in village-level aggregation centers and strengthen primary agricultural cooperatives to pool transport logistics and enhance collective bargaining power.

2. Infrastructure Investment and Value Chain Formalization for Soybean

To resolve structural value chain asymmetries between East and West Hararghe, targeted public-private partnerships (PPPs) must be established in the soybean sector. Interventions should focus on establishing decentralized regional processing units, formalizing contract farming schemes, and directly linking soybean producers with central feed manufacturers and industrial oil processors to dismantle monopsonistic buyer bottlenecks.

3. Lower Initial Entry Barriers for Vulnerable Demographic Groups

Because female-headed households and geographically remote farmers face acute structural exclusions at the subsistence threshold, early-stage interventions must be explicitly targeted. Policy measures should enforce gender-equitable access to productive land, credit, and extension,

while establishing local, decentralized assembly markets to minimize initial transport overheads for isolated farmers.

4. Restructure Rural Credit from Survival Buffers to Productive Capital

Financial institutions and microfinance organizations operating in rural Oromia should move away from small-scale, short-term seasonal input loans that are routinely consumed as pre-harvest survival buffers. Credit products should be redesigned as medium-term, asset-building commercial packages tied to small-scale farm machinery, irrigation pumps, or post-harvest storage facilities with repayment schedules aligned with commercial crop marketing cycles.

5. Institutionalize Tiered Agricultural Extension Advisory Models

Public agricultural extension programs should officially adopt a tiered advisory model tailored to commercial readiness:

- **Tier 1 (Subsistence Households):** Maintain focus on baseline food security, agronomic best practices, and yield risk mitigation.
- **Tiers 2–4 (Semi-Commercialized to High-Intensity):** Fast-track farmers into specialized agribusiness modules covering post-harvest loss reduction, quality compliance standards, digital price discovery, and contractual negotiations.

6. Implement Nutrition-Sensitive Commercialization Interventions

To resolve the dietary diversity paradox, commercialization policies must not operate in isolation from rural food environments. Regional agricultural and health agencies should promote nutrition-sensitive value chains by:

- Encouraging smallholders to retain dedicated home gardens and diverse intercropping plots to prevent total monoculture displacement.
- Delivering behavioral change communication on household nutritional budget allocation.
- Supporting regional food market formalization to improve the local retail supply of non-local nutrient-dense foods (e.g., fresh dairy, fruits, and animal-source proteins).

7. Strategic Priority: Prioritize Sub-Subsistence Transitions

Because the only statistically significant dividend in caloric security occurs during the initial shift out of autarky, public funds yield the highest social return when assisting pure subsistence smallholders to cross the entry threshold into semi-commercial status. Resources should not focus solely on expanding production among the high-intensity commercial elite, but rather on pulling resource-poor subsistence growers into basic market engagement via targeted input subsidies and aggregation infrastructure.

5.3. Future Research Directions

While this study provides robust empirical evidence on smallholder commercialization dynamics in Hararghe , Eastern Ethiopia, several critical avenues remain open for future scholarly inquiry:

1. **Longitudinal Panel Data Analysis:** This study relied on cross-sectional survey data from 383 households. Future research should utilize multi-wave panel datasets to observe dynamic commercial mobility over time, evaluate how households transition across tiers throughout favorable and unfavorable climate cycles, and control for unobserved household heterogeneity.
2. **Intra-Household Income Control and Gender Dynamics:** Gender dynamics at upper commercial tiers warrant deeper qualitative and intra-household quantitative investigation. Future studies should analyze how control over cash income shifts between male and female spouses as crop enterprises transition from subsistence foodstuffs to commercialized cash crops, and how this reallocation impacts intra-household nutritional spending.
3. **Continuous GPS Treatment Dosage and Non-Parametric Modeling:** While this study applied multivalued IPWRA across discrete tiers, future empirical work could apply continuous Generalized Propensity Score (GPS) dose-response functions to map exact continuous threshold cut-offs (HCI $\in [0, 1]$) where nutritional returns flatten or turn negative.
4. **General Equilibrium and Regional Food Market Dynamics:** Further research should empirically model rural food market structures in regional centers to evaluate price

transmission, seasonal retail availability of nutrient-dense foods, and the macro-level impact of oilseed expansion on local staple food supply chains.

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Author contributions

Admkew Haile: conceptualization, data curation, formal analysis, methodology design, validation, visualization, writing original draft, writing review, and editing. Mengistu Ketema: conceptualization, data curation, investigation, methodology development, supervision, visualization, and editing. Mulugeta Damie: conceptualization, investigation, proposal development, and editing. Ketema Bekele: conceptualization, formal analysis, methodology development, validation, visualization, and editing. All authors read and approved final manuscript.

Competing interests:

The authors declare no competing interests.

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Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration

Ethics

The study received ethical approval from Haramaya University of Doctoral Committee of the School of Agricultural Economics and Agribusiness, Ethics Committee ((R-04)/22-01-2025). All research procedures were performed in accordance with the ethical guidelines and regulations of Haramaya University and the principles outlined in the Declaration of Helsinki.

Accordance / Ethical Guidelines Statement

All procedures involving human participants were conducted in accordance with relevant institutional guidelines and ethical standards for educational research and in accordance with the principles of the Declaration of Helsinki.

Consent to participate

Informed consent was obtained from all individual subjects included in this study. All survey respondents were fully informed about the study's scientific purpose, the voluntary nature of their participation, and data security procedures. Participation was restricted to individuals aged 18 or older who provided informed consent prior to the commencement of the interviews.

Use of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used Gemini solely to edit the text for language accuracy and improve overall readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Consent to publish: Not applicable.

Clinical trials: Not applicable

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Appendices

