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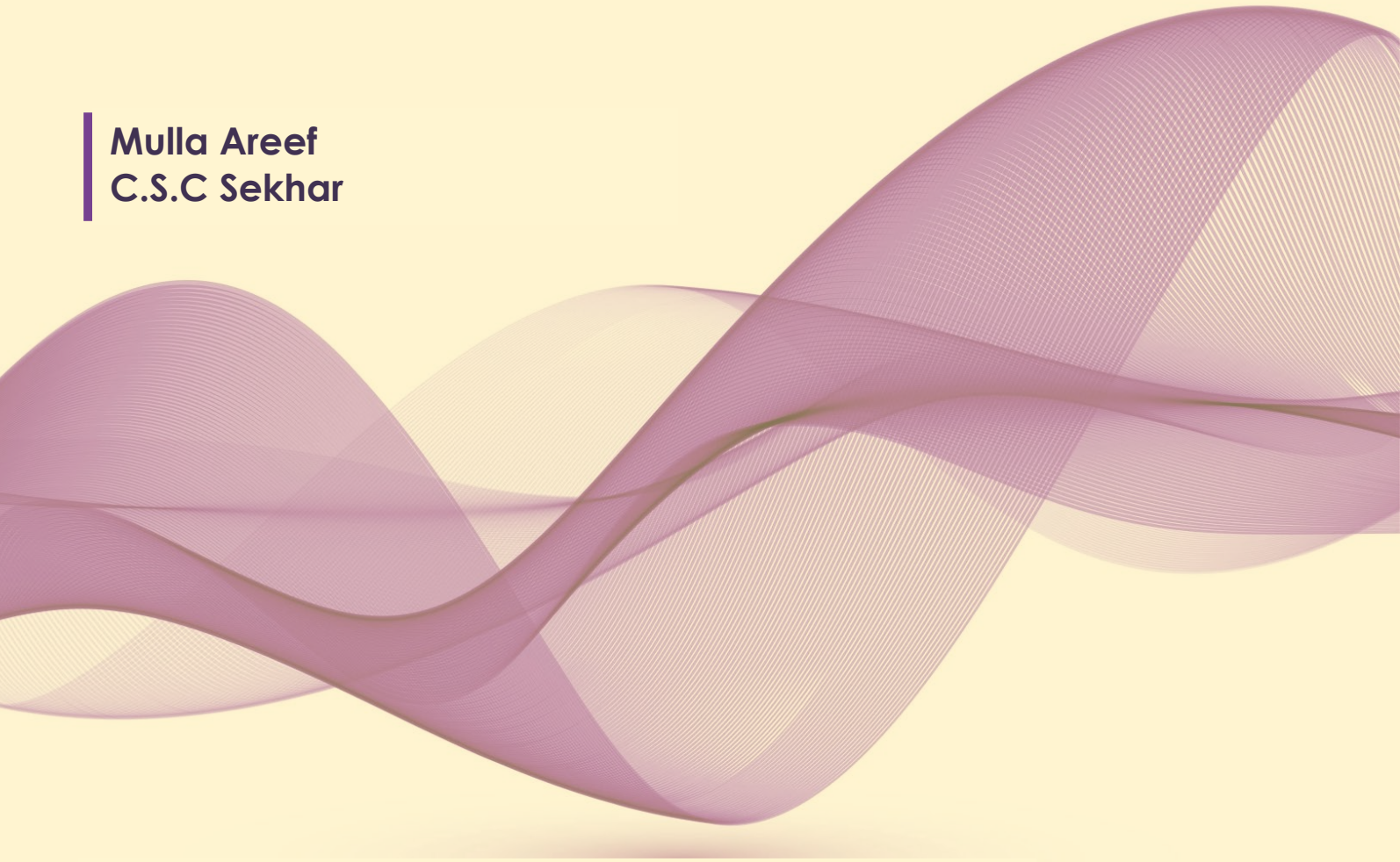

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Is Income Diversification Welfare-Enhancing? Empirical Evidence on Smallholder Resilience to Climate Shocks in India

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Abstract

In developing economies, rural households are engaging in livelihood diversification as a strategy to stabilize income and manage risk. This study examines the relationship between climate shocks, income diversification, and household welfare in rural India, a nexus that remains underexplored in the existing literature. Using pooled panel data from the 2012–13 and 2018–19 rounds of the Situation Assessment Survey, the analysis identifies the determinants of income diversification and estimates its causal impact on household welfare, measured by monthly per capita income (MPCI) and consumption expenditure (MPCE). A tri-econometric strategy is adopted, including fixed effects estimation, Pearl's front-door criterion (FDC) approach with seemingly unrelated regression (SUR) framework, and two-stage least squares (2SLS). The FDC results indicate that non-farm income acts as a partial mediator in the income diversification–welfare pathway, though the estimated effects are weaker than those from 2SLS. Under the 2SLS framework, diversification is associated with a 56 to 63% increase in MPCI and a 7 to 10% increase in MPCE. However, the welfare benefits of diversification are attenuated for households exposed to climate shocks. Marginal landholders in India exhibit income specialization, contrasting with the diversification strategies of smallholders in developed countries. We test for both linear and non-linear effects of income diversification on MPCI and MPCE, finding support for a positive and linear relationship, with heterogeneous effects based on the intensity of diversification. Despite favoring wealthier households, income diversification remains essential for smallholders, warranting inclusive, region-specific strategies (such as MGNREGA support and targeted investment in local farming systems) to promote resilience and equitable rural transformation.

Keywords: Climate shocks, income diversification, non-farm income, agricultural households & India.

JEL Codes: Q12, Q54, D10, O13, R11.

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1. Introduction

In India, agriculture remains a major source of livelihood for a majority of rural households. However, the sector faces mounting challenges arising from both climate shocks and market uncertainties, including price fluctuations. In response to these risks, rural households increasingly adopt livelihood diversification strategies to stabilize incomes and manage risk. Decline or stagnation in cultivation income, alongside climate-related shocks, has contributed to a gradual shift toward more remunerative other income sources in India. Rural transformation has historically been driven by institutional improvements, market expansion, crop shifts toward high-value produce, and increased rural-urban economic linkages, including non-farm employment opportunities and migration (Davis et al., 2025). Rural households in low- and middle-income countries engage in diverse livelihood strategies beyond crop and livestock production, with patterns of diversification evolving alongside structural transformation (Barrett et al., 2001; Davis et al., 2017; De la O Campos et al., 2025). Constraints including land scarcity, soil degradation, and limited access to markets, credit, and extension services frequently push households toward non-farm employment, which also serves as a risk-coping mechanism (Lowder et al., 2025). The seasonality of agricultural employment further facilitates diversification by creating periods of labor availability for alternative income-generating activities. Wage employment increasingly supplements and stabilizes rural household incomes over time in Africa (Khan & Morrissey, 2023; Mutsami et al., 2025; Van den Broeck & Kilic, 2019). In the Indian context, the share of the rural workforce engaged in non-farm activities increased markedly, rising from 21.6 percent in 1993–94 to 42.2 percent by 2018–19 (Pattayat and Parida, 2024).

Income diversification is a widespread livelihood strategy among rural households in developing countries, often pursued as a response to income volatility, economic constraints, or environmental shocks (Barrett et al., 2001; Reardon et al., 2001; Gautam & Andersen, 2016; Musumba et al., 2022). The decision to diversify depends on household-specific characteristics, including asset endowments, income levels, and the nature of local employment opportunities. While diversification can enhance household income and resilience, it is not uniformly accessible. Wealthier, asset-rich households are more likely to engage in high-return, capital-intensive nonfarm activities, thereby reinforcing income inequality (Barrett et al., 2001; Losch et al., 2012). In contrast, poorer households often face significant entry barriers to such opportunities. The choice between specialization and diversification is shaped by economies of scale and scope, risk preferences, and contextual factors such as geography and infrastructure (Wuepper et al., 2018). Recent work highlights the limited attention given to the role of regional and

environmental determinants in shaping diversification patterns (Grilli et al., 2024). Rural nonfarm employment (RNFE) has expanded in response to accelerating urbanization, structural economic transformation, and a series of economic, climatic, and health-related shocks. Across developing economies, the RNFE constitutes a major share of household income, accounting for about 35% in Africa and up to 50% in Latin America and the Caribbean (Haggblade et al., 2007). Across developing and transition economies indicate that RNFE comprises 58% on average, peaking at 75% in some countries (Davis et al., 2009). Both farm-linked and non-agricultural RNFE segments have grown, with implications for income diversification, resilience, and labor allocation (Hazell et al., 2024). Engagement in RNFE often serves as a coping strategy against farm income volatility induced by agro-climatic shocks (Drall & Mandal, 2025), underscoring its role in rural household risk management. While a growing body of literature examines the effects of non-farm income on agricultural production (Kilic et al., 2009; Pfeiffer et al., 2009; Phimister & Roberts, 2006; Drall & Mandal, 2025), relatively less attention has been given to its implications for household welfare outcomes.

In India, empirical evidence on the determinants and impacts of diversification remains limited. Most existing studies rely on cross-sectional data, restricting the ability to capture dynamic processes or infer causal relationships over time. Moreover, much of the existing literature relies on a binary dummy for income sources (farm versus non-farm) thereby overlooking more refined measures of diversification intensity. Continuous and multidimensional indices, such as the Ogive Specialization Index (OSI) and the Simpson Diversification Index (SDI), provide richer representations of household income portfolios but remain underutilized in empirical research. These limitations are particularly salient in the context of structural transformation and increasing exposure to climate-related shocks, which necessitate more nuanced and longitudinal analyses.

Despite growing interest in household risk-coping strategies, limited empirical evidence exists on the nexus between climate shocks, income diversification, and welfare outcomes in India. This study contributes to this literature by leveraging panel data to investigate the determinants of income diversification and its causal impacts on household welfare. Further, we examine whether income diversification has a positive and linear impact on MPCI and MPCE, with heterogeneous effects across households depending on the level of diversification.

The remainder of the paper is structured as follows. Section 2 presents the data and summary statistics. Section 3 outlines the estimation strategy used to examine the pathways through which diversification is hypothesized to impact welfare outcomes. Section 4 reports the empirical findings, while Section 5 discusses their implications. Section 6 concludes.

2. Data and definition of variables

2.1. Situation assessment survey of agricultural households

This study utilizes data from two rounds of Situation Assessment Survey (NSSO-SAS), the most recent and directly comparable rounds due to uniform definitions of agricultural households. Prior studies have largely relied on broader rural household samples, by contrast, this study focuses solely on agricultural households, offering a more targeted examination of livelihood strategies and welfare outcomes. Both surveys employed a stratified multi-stage sampling design, with census villages as primary units and agricultural households as ultimate sampling units. The 2012–13 round included 35,200 households, while the 2018–19 round covered 44,770, yielding rich data on agricultural practices and socioeconomic conditions. For estimation, we use 34,350 households across 4,443 villages and 625 districts (2012–13) and 44,462 households from 5,732 villages and 657 districts (2018–19), constructing a pooled cross-sectional dataset of 78,812 observations. Given that households are not tracked over time, we assume that observations across survey rounds as independent but not identically distributed, consistent with econometric conventions for pooled cross-sectional analysis (Mundlak, 1978; Wooldridge, 2010).

2.1.1. Outcome variables

We employ monthly per capita household income (MPCI) and monthly per capita consumption expenditure (MPCE) as key indicators of household welfare. Household income and consumption expenditure are measured in per capita terms by dividing total values by household size. Total household income comprises net earnings from crop cultivation, livestock rearing, non-farm business activities, wages and salaries, rental income from leased-out land, and transfer payments, including pensions and remittances. Consumption expenditure reflects total monthly household spending on both food and non-food items.

Although equivalence scales offer greater precision by accounting for individual needs and economies of scale, their application differs conceptually between income and consumption, complicating intra-household resource allocation. Meenakshi and Ray (2002) cautioned that using household size alone may misestimate poverty by ignoring adult–child consumption differences and scale economies. Moreover, constructing income-based equivalence scales poses challenges due to heterogeneity in earning capacities. For consistency and comparability, this study adopted the standard per capita approach for both income and consumption. Robustness checks using alternative specifications (total monthly household income and consumption expenditure) support the robustness of our findings.

2.1.2. Measures of income diversification

To measure income diversification, we employ the Ogive index (Ali et al., 1991), which captures inequality in income distribution across sources and is sensitive to both the number of sources and structural dependence on any single one. As a robustness check, we use the Simpson index, commonly applied in agricultural diversification studies (Joshi et al., 2004; Babatunde and Qaim, 2009; Khatun and Roy, 2012; Guthoff et al., 2024), which reflects the evenness of income shares but may understate skewness. Both indices incorporate income from cultivation, livestock, non-farm business, wages or salaries, rental earnings from leased-out land, and transfer payments. Using both measures allows us to account for distinct aspects of diversification (dominance and evenness) thereby enhancing the robustness of our analysis.

These indices are given by:

$$\text{Ogive specialisation index (OSI)} = \sum_{n=1}^{N} \frac{\left(X_n - \frac{1}{N}\right)^2}{\frac{1}{N}}, \quad 0 \leq \text{OSI} \leq (N-1) \text{ (Fully specialised)}$$

$$\text{Simpson diversity index (SDI)} = 1 - \sum_{n=1}^{N} (X_n)^2, \quad 0 \leq \text{SDI} \leq 1 \text{ (Fully diversified)}$$

where N denote six income sources for household i, and Xn represents the share from source n (cultivation, livestock, non-farm business, wages, rental income, and transfers). OSI ranges from 0 (complete diversification) to 5 (full specialization), while SDI ranges from 0 (specialization) to 1 (complete diversification).

Figure 1 displays kernel density estimates of the OSI and the SDI to examine the distributional patterns of agricultural household income across 2012–13 and 2018–19. Both indices measure income diversification, but the OSI is particularly useful when dominance by a single income source is analytically salient, providing a more intuitive measure of

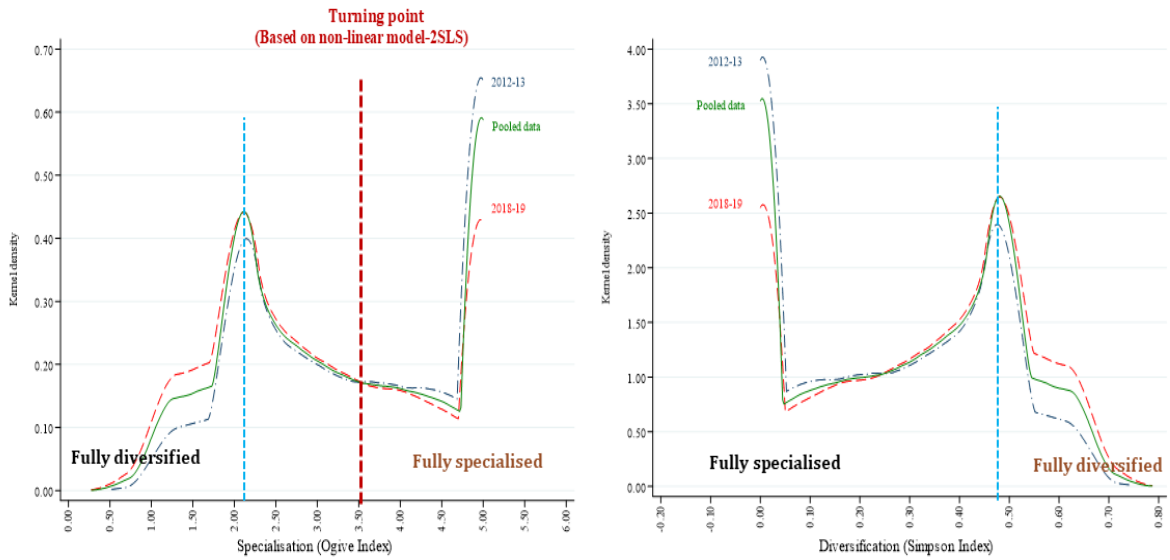

Figure 1. Income diversification distribution
Source: *Authors' calculations from NSSO-SAS unit level data, 2012-13 and 2018-19.*

household reliance on the primary source of income. The OSI estimates (left panel) exhibit a concentration around a mid-range value (2), indicating that a significant share of households maintained moderately diversified income portfolios. This concentration becomes more pronounced in 2018–19, suggesting a shift toward mixed livelihood strategies. This pattern likely reflects household responses to evolving rural labor markets, including greater engagement in non-farm employment, expansion of public works programs such as MGNREGS, and increased participation in informal self-employment. The SDI kernel density estimates (right panel) reinforce this trend, the density of households with moderate diversification (0.45–0.55) increases in 2018–19, while the share with very low diversification (near zero) declines. Taken together, the kernel density estimates of OSI and SDI point to a gradual structural transformation in the rural economy, where income diversification emerges possibly as a risk-coping mechanism and a response to changing opportunity structures.

2.1.3. Risk exposure variables

To examine household exposure to market, production, and climate risks, we construct three binary indicators representing price shocks, yield shocks, and climate shocks. The price shock variable is generated using value-weighted average crop prices at the household level and village-level averages of paid-out expenses and output prices. A household is classified as experiencing a price shock if paid-out expenses exceed the village average

by more than 20%, or output prices fall more than 20% below it. For yield shocks, we compute household-level yields (output per unit of cultivated land) and compare them to village-level averages. A household is coded as having experienced a yield shock if its yield is less than 80% of the village mean, following established methods (Christensen 1975; Doss 2018; Drall and Mandal 2025). The climate shock variable relies on farmer-reported crop loss due to adverse weather events such as droughts, floods, or other natural calamities. It takes the value 1 if household attributes crop loss to any such event. To analyze whether income diversification buffers climate-induced welfare risks, we interact the climate shock indicator with the OSI and the SDI. In contrast to price and yield shocks, which may reflect idiosyncratic factors or market-level fluctuations, climate shocks are exogenous and covariate. Their systemic nature enables a more credible identification of household vulnerability and the potential protective role of diversification.

2.1.4. Mediator and instrumental variables

We hypothesize that income diversification affects household welfare through its impact on the share of nonfarm income, which serves as a mediating channel. Diversification facilitates the reallocation of labor and resources toward non-agricultural activities, including wage employment, services, and self-employment. This shift, captured by a higher non-farm income share, mediates the relationship between diversification and welfare outcomes. The conceptual foundation for this pathway is rooted in the rural transformation literature, which identifies structural shifts in livelihood portfolios as key drivers of income growth and economic resilience (Barrett et al., 2001; Haggblade et al., 2007; Hazell et al., 2024). Empirical evidence from developing countries further support this pathway, showing that non-farm engagement is positively associated with household income (Lanjouw & Lanjouw, 2001).

A key empirical challenge in assessing the relationship between income diversification and household welfare is endogeneity, particularly due to potential reverse causality. To address the potential endogeneity of the OSI, we instrument with village population and non-farm asset value, capturing demand-side and supply-side factors, respectively. Village population proxies local market access and employment density, influencing specialization decisions while plausibly unrelated to current welfare. Non-farm assets reflect households' pre-existing capacity to engage in non-agricultural activities, shaping income strategies without directly affecting short-term welfare outcomes such as consumption or income. These instruments satisfy relevance by influencing OSI and meet the exclusion restriction under the assumption that they affect welfare only through specialization, consistent with prior empirical evidence (Babatunde & Qaim, 2009).

3. Estimation Strategy

3.1. Theoretical framework

To address our research objective, the Agricultural Household Model (Singh et al., 1986) has been used, which captures utility-maximizing decisions under resource and market constraints by integrating production, consumption, and labor allocation across farm and non-farm activities. This framework underscores how income diversification influences household welfare through interdependent economic choices. We also build on the Livelihood Diversification Framework (Ellis, 1998; Barrett et al., 2001), which conceptualizes diversification as a risk-management strategy in response to shocks common in rural settings (Dercon, 2002). Together, these models provide a theoretical basis for analyzing how income diversification affects income stability, consumption smoothing, and resilience, with implications for improving smallholder farmers well-being.

3.2. Determinants of income diversification

Given that the Ogive specialization index is censored between zero and five, a Tobit model is employed (De Janvry & Sadoulet 2001; Woldenhanna & Oskam 2001; Babatunde & Qaim 2009). Assuming normally distributed errors, the Tobit model ensures consistent estimates (Loudermilk 2007). The following specification is used to identify key determinants of income diversification:

$$OSI_{it}^{*} = \beta_0 + \beta_x X_{it}' + \beta_x Z_{it} + \lambda_i + \eta_t + \varepsilon_{it} \tag{1}$$

where OSI_{it}^{*} is a latent variable, which is unobserved for values below the lower limit and above the upper limit, and represents the Ogive Specialisation Index. The vector X_{it}' comprises baseline control variables, including age of the household head, female-headed household, household head education, household size, caste, marginal farmer household, owned land size, share of irrigated to operational land, access to crop markets, access to extension services, access to credit, cooperative membership, MGNREGA job card holder, awareness of minimum support price, exclusive cultivation of cereals, price shock, yield shock, and climate shock. The vector Z_{it} includes additional control variables, namely non-farm income share, village population, and non-farm asset value. The vector β_x contains the parameters to be estimated. We also include district fixed effects (λ_i) to account for time-invariant heterogeneity, while time fixed effects (η_t) capture policy shifts over time. The error term is denoted by ε_{it}.

3.3. Impacts of income diversification

Estimating the causal effect of income diversification on household welfare is complicated by endogeneity arising from both omitted variable bias and potential reverse causality. On the one side, diversification decisions may be driven by unobserved factors (such as risk preferences, entrepreneurial ability, or access to informal networks) that also influence welfare outcomes. On the other side, reverse causality arises if higher-welfare households are better positioned to diversify, thereby complicating identification of the causal direction. To address these challenges, this study adopted a sequential identification strategy. First, OLS models with district fixed effects control for time-invariant spatial heterogeneity. Second, the front door criterion (FDC) approach with seemingly unrelated regression (SUR) framework estimates the causal effect through a mediating variable, offering robustness against unobserved confounders. Third, two-stage least squares estimation using generalized method of moments (2SLS-GMM) to address potential endogeneity arising from reverse causality. Each method targets a distinct source of bias, and their combined application enables triangulation of results. This approach not only strengthens causal inference but also facilitates decomposition of the pathways linking diversification to welfare.

3.3.1. Baseline fixed effects model

We employ a fixed effects linear regression model to control for unobserved, time-invariant district-level heterogeneity and temporal shocks. To capture the conditioning role of climate shock, we include a dummy variable indicating household exposure to extreme climate shocks. Such exposure may attenuate welfare gains from diversification by disrupting agricultural and non-farm incomes. An interaction term between the OSI and the climate shock is incorporated to examine whether the relationship between income diversification and welfare outcomes varies systematically with climate-related vulnerability. The baseline specification is given as follows:

$$Y_{it} = \beta_0 + \beta_s OSI_{it} + \beta_c CS_{it} + \beta_{sc} \left[OSI_{it} \times CS_{it} \right] + \beta_x x_{it} + \lambda_i + \eta_t + \varepsilon_{it} \qquad (2)$$

where Y_{it} denotes the natural logarithm of welfare outcomes (measured by MPCI and MPCE) for household i at time t. OSI_{it} is the Ogive Specialisation Index, and CS_{it} is a binary indicator equal to 1 if the household experienced a climate shock (e.g., drought, flood, or other natural hazard). The interaction term $OSI_{it} \times CS_{it}$ captures whether the effect of income specialisation varies with climate exposure. The vector x_{it} includes baseline controls identical to those in Equation (1) of the Tobit model. We include district

fixed effects (λ_i) to control for time-invariant observed and unobserved heterogeneity, and time fixed effects (η_t) to account for temporal shocks and policy changes. The error term ε_{it} captures idiosyncratic shocks, with standard errors clustered at the village level to correct for heteroskedasticity and intra-village correlation. The parameter β_s estimates the average effect of diversification on welfare outcomes.

3.3.2. Front Door Criterion approach with SUR framework

While fixed effects estimation controls for time-invariant unobserved heterogeneity, it may not adequately address endogeneity stemming from time-varying omitted variables or simultaneity. To strengthen causal identification, we employ the Front-Door Criterion (FDC) as proposed by Pearl (1995), which allows identification even when conventional back-door strategies fail due to unobserved confounding between the treatment and the outcome. In this context, we specify a causal ordering from the Ogive Specialisation Index (OSI) to the share of non-farm income (M), and subsequently to household welfare outcomes (Y). The non-farm income share (M) serves as a relevant mediator, capturing the reallocation of household labor and resources from farm to non-farm activities.

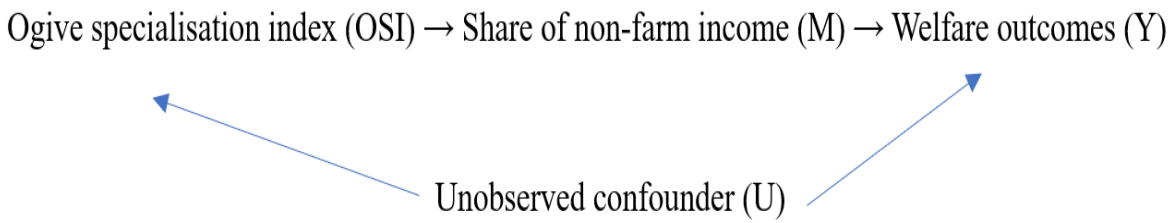

Figure 2. The front-door criterion

To ensure credible identification of the structural pathway, we control for an extensive set of observable household, farm, and risk exposure characteristics that may confound either segment of the causal chain. The analysis treats the share of non-farm income as a mediator between the Ogive specialization index and welfare outcomes. Identification rests on the sequential ignorability assumption (Rosenbaum and Rubin, 1983; Bellemare et al., 2024), positing no unobserved confounding of the Ogive–mediator and mediator–outcome relationships, conditional on covariates. While inherently untestable, this assumption is supported through rich controls and robustness checks. The FDC framework allows us to estimate the indirect effect of diversification through structural shifts in income composition, thereby elucidating a key mechanism through which income diversification may enhance household welfare.

We estimate the FDC using a seemingly unrelated regressions (SUR) framework (Zellner, 1962), allowing for efficient inference while accounting for residual correlation between stages. The estimation involves specifying and jointly estimating the following system of equations.

$$\text{FDC First Stage:} \quad M_{it} = \theta_0 + \gamma_s OSI_{it} + \beta_{sc}\left[OSI_{it} \times CS_{it}\right] + \beta_x x_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (3)$$

$$\text{FDC Second Stage:} \quad Y_{it} = \phi_0 + \delta_s M_{it} + \tau_s OSI_{it} + \beta_{sc}\left[OSI_{it} \times CS_{it}\right] + \beta_x x_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (4)$$

where M_{it} is the share of non-farm income, Y_{it} denotes the natural logarithm of welfare outcomes, and OSI_{it} represents the Ogive Specialization Index. The vector x_{it} includes baseline controls, while λ_i and η_t capture district and time fixed effects, respectively. ε_{it} denotes the idiosyncratic error term. Under the identifying assumption that OSI_{it} affects welfare solely through the specified causal pathway, conditioning on x_{it} blocks observed backdoor paths between OSI_{it} and Y_{it}. The causal effect of OSI_{it} on Y_{it} is computed by multiplying the estimated coefficients $\hat{\gamma}_s$ and $\hat{\delta}_s$.

3.3.3. Two-stage least squares estimation (2SLS)

While the FDC provides a strong identification strategy, its reliance on structural assumptions necessitates robustness checks. Accordingly, we also estimate a two-stage least squares model using the generalized method of moments, offering an alternative identification approach less dependent on structural assumptions. The following 2SLS Model has been estimated.

$$Y_{it} = \beta_0 + \beta_s \hat{OSI}_{it} + \beta_{sc}\left[OSI_{it} \times CS_{it}\right] + \beta_x X'_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (5)$$

where Y_{it} denotes the log of welfare outcomes, while OSI_{it} represents the Ogive specialisation index. The model includes baseline controls x_{it}, district fixed effects λ_i, time fixed effects η_t, and error term ε_{it}. To address endogeneity, we instrument OSI_{it} with log village population and log nonfarm asset value. The coefficient β_s reflects the average effect of diversification on welfare outcomes, though it lacks structural interpretation. To assess elasticities, we compute marginal effects, estimating the percentage change in welfare outcomes from a 1% increase in diversification (Juvancic & Erjavec, 2005; Yu & Babcock, 2010).

3.3.4. Tests of instrumental variables

The first-stage regression results (Table A1) confirm that the instruments (village population and nonfarm asset value) are strongly correlated with the endogenous variable (OSI), satisfying the relevance condition for IV estimation. Table A2 presents standard validity tests assessing instrument strength and exogeneity. The Kleibergen–Paap rk LM statistic indicates no under-identification, while both the Cragg–Donald Wald F and the Kleibergen–Paap rk Wald F statistics exceed the Stock–Yogo critical values at the 10% maximal IV size, indicating strong instruments with limited bias in IV estimates.

Although the exclusion restriction is not directly testable, theoretical justification is provided, and the Hansen J test offers statistical evidence. An insignificant J statistic supports the hypothesis that the instruments affect the outcome only through OSI. However, caution is warranted in the pooled MPCE specification, where the J test indicates potential over-identification. Overall, the instruments satisfy both relevance and exogeneity conditions, reinforcing the robustness of the IV strategy in addressing endogeneity in the diversification-welfare relationship.

4. Results

4.1. Summary statistics

Table 1 reports descriptive statistics for selected household and production characteristics across the 2012–13 and 2018–19 survey rounds, disaggregated by household type (partially diversified and fully specialized). Average age and gender of household heads remained stable across years, though female-headed households were slightly more prevalent among fully specialized households (10%) compared to partially diversified ones (8%). Partially diversified households exhibited larger sizes and older household heads. Landholding sizes showed little variation across years or household categories. The share of operational area under irrigation increased substantially from 19.2% in 2012–13 to 49.2% in 2018–19, reflecting significant improvements in irrigation access. However, irrigation shares were nearly identical across household types in 2018–19, suggesting that this expansion was exogenous to household diversification strategies. This pattern likely reflects broader public investments or climate adaptation responses. The proportion of marginal farmer households rose from 0.49 to 0.59 over the period, with slightly higher shares among partially diversified households.

Table 1. Summary statistics (in 2011–12 constant prices, deflated using CPI-AL)

Variables	Across years		Across household type[a]		
	2012–13	2018–19	Partially diversified	Fully specialised	Pooled
Demographic and Household Characteristics					
Age of household head (years)	50.67***	51.01	50.91**	50.65	50.86
	(13.44)	(13.39)	(13.34)	(13.72)	(13.41)
Female-headed household (dummy)	0.08**	0.09	0.08***	0.10	0.08
	(0.28)	(0.28)	(0.27)	(0.30)	(0.28)
Household size (number)	5.38***	4.98	5.27***	4.67	5.15
	(2.69)	(2.36)	(2.53)	(2.41)	(2.52)
Primary education	0.26***	0.41	0.35***	0.31	0.34
	(0.44)	(0.49)	(0.48)	(0.46)	(0.47)
Secondary education	0.28***	0.12	0.18***	0.23	0.19
	(0.45)	(0.33)	(0.39)	(0.42)	(0.39)
Higher secondary and above	0.11***	0.13	0.12***	0.13	0.12
	(0.31)	(0.34)	(0.33)	(0.34)	(0.33)
OBC (1=yes)	0.40***	0.41	0.40***	0.43	0.41
	(0.49)	(0.49)	(0.49)	(0.50)	(0.49)
SC/ST (1=yes)	0.32***	0.34	0.35***	0.26	0.33
	(0.47)	(0.47)	(0.48)	(0.44)	(0.47)
Landholding and Farm Characteristics					
Owned land size (acres)	2.51NS	2.49	2.49NS	2.52	2.50
	(4.13)	(3.16)	(3.61)	(3.66)	(3.62)
Share irrigated land (%)	19.18***	49.23	36.21NS	35.80	36.13
	(37.70)	(45.19)	(44.49)	(45.29)	(44.65)
Marginal farmer (1=yes)	0.49***	0.59	0.55***	0.52	0.55
	(0.50)	(0.49)	(0.50)	(0.50)	(0.50)
Exclusive cereals (dummy)	0.77***	0.78	0.79***	0.71	0.78
	(0.42)	(0.41)	(0.41)	(0.46)	(0.42)
Access to Services and Programs					
Access to crop markets	0.69***	0.75	0.73***	0.70	0.73
	(0.46)	(0.43)	(0.44)	(0.46)	(0.45)
Access to extension	0.47***	0.59	0.55***	0.49	0.54
	(0.50)	(0.49)	(0.50)	(0.50)	(0.50)
Access to credit	0.52***	0.50	0.51***	0.49	0.51
	(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Farmer cooperative membership	0.12***	0.05	0.08***	0.07	0.08
	(0.32)	(0.21)	(0.27)	(0.25)	(0.27)
MGNREGA job card holder	0.45***	0.44	0.47***	0.34	0.45
	(0.50)	(0.50)	(0.50)	(0.47)	(0.50)
Awareness of MSP	0.27***	0.32	0.31***	0.27	0.30
	(0.44)	(0.47)	(0.46)	(0.44)	(0.46)
Risk Exposure					
Price shock	0.43***	0.33	0.37**	0.38	0.38
	(0.50)	(0.47)	(0.48)	(0.49)	(0.48)
Yield shock	0.46***	0.37	0.40***	0.45	0.41
	(0.50)	(0.48)	(0.49)	(0.50)	(0.49)
Climate shock	0.31***	0.35	0.33**	0.34	0.33
	(0.46)	(0.48)	(0.47)	(0.47)	(0.47)
Diversification Measure					
Ogive specialisation index (0–5)	3.44***	3.04	2.79***	5.00	3.22
	(1.26)	(1.27)	(1.04)	(0.00)	(1.28)
Income and Consumption					
Monthly per capita income (INR)	1848.18***	2005.97	2081.25***	1335.19	1937.20
	(3930.82)	(3841.21)	(3971.01)	(3416.34)	(3881.28)
Monthly per capita consumption (INR)	1338.66***	1424.79	1367.42***	1470.13	1387.25
	(3248.26)	(776.28)	(1049.56)	(4580.00)	(2222.71)
Mediator and Instrumental Variables					
Share income from non-agriculture (%)	34.50***	41.71	43.89***	16.32	38.56
	(37.46)	(37.36)	(35.73)	(36.96)	(37.58)
Village population (log)	16.25***	10.49	12.84***	13.68	13.00
	(1.21)	(1.52)	(3.15)	(3.19)	(3.18)
Non-farm asset value (log)	0.19***	0.10	0.15***	0.08	0.14
	(1.19)	(0.86)	(1.07)	(0.76)	(1.02)
Number of observations	34350	44462	63595	15217	78812

Note: Significant differences are indicated with *** $p < 0.01$, ** $p < 0.05$, or NS = insignificant. Standard deviations are in parentheses.

[a] Households with an Ogive index of 5 are fully specialised; values < 5 indicate partial diversification across income sources.

Source: Authors' calculations from NSSO-SAS unit level data, 2012–13 and 2018–19.

Access to crop markets increased from 69% to 75%, and extension services from 47% to 59%, indicating improved infrastructure and outreach between 2012–13 and 2018–19. Credit access remained stagnant at approximately 50%, underscoring persistent financial constraints. Partially diversified households reported greater access to markets and extension services than fully specialized ones, suggesting broader service needs. Credit access showed little variation across household types. Cooperative membership declined from 12% to 5%, with slightly higher participation among diversified households. MGNREGA job card ownership held steady at 45%, yet was more common among diversified households, indicating reliance on non-farm income. Awareness of minimum support prices rose modestly, with higher levels among diversified households, reflecting increased market engagement. Between 2012–13 and 2018–19, reported price and yield shocks declined, while climate shocks increased slightly, indicating persistent climate risks. Fully specialized households faced greater exposure to yield and climate shocks than partially diversified ones, highlighting diversification's buffering role. The OSI declined from 3.44 to 3.04, with lower OSI value (2.79) among diversified households, signaling a shift toward broader income sources and greater diversification.

Monthly per capita household income increased modestly from INR 1848 in 2012–13 to INR 2006 in 2018–19, with diversified households earning significantly more (INR 2081) than specialized ones (INR 1335), highlighting economic gains from diversification. Partially diversified households earned substantially more (INR 2,081) than fully specialized ones (INR 1335), suggesting income benefits from diversification. However, diversified households reported higher income but lower consumption than specialized ones. This pattern may reflect precautionary saving behavior due to income volatility, and irregular non-farm earnings, suggesting that income gains from diversification do not necessarily translate into higher consumption.

The share of non-farm income rose from 35% to 42%, with partially diversified households deriving 44% of income from non-agriculture, compared to 16% among specialized households, consistent with patterns observed across developing economies (Haggblade et al. 2007; Davis et al. 2009). Farm households earn nearly half their income from non-farm activities, especially smallholders, highlighting income diversification's role amid land constraints (Birthal et al., 2014). Specialized households reside in larger villages but hold fewer non-farm assets, reflecting trade-offs between specialization and diversification in rural livelihoods.

4.2. Determinants of Household Income Diversification: Tobit Model Estimates

The Tobit regression results presented in Table 2 and revealed that both household and institutional factors significantly influence income diversification. A negative marginal effect denotes greater diversification. Female-headed households are more income-specialized, likely due to persistent constraints in accessing land and productive assets (Gladwin et al. 2001). Household size consistently shows a negative and statistically significant association with the index across all model specifications (2012-13, 2018-19, and pooled), indicating that larger households tend to diversify more. Specifically, a one unit increase in household size is associated with a 4 percent decline in specialization, suggesting that greater household labor availability facilitates engagement in a broader range of income-generating activities.

Belonging to socially disadvantaged groups, particularly OBC and SC/ST households, is consistently associated with higher income diversification. SC/ST households, on average, exhibit 7 to 10% higher diversification indices than upper-caste counterparts, likely reflecting risk-coping responses to limited access to high-return farm opportunities. Marginal landholders show a distinct pattern, while their effect on specialisation was insignificant in earlier periods, it becomes positive and significant in 2018-19 and pooled models, indicating a shift toward income specialization. Owned land shows a significantly positive association with specialization in 2012–13 and pooled models, but insignificant in 2018–19, indicating a declining influence of land ownership over time.

Institutional factors also play a role, households with access to crop markets, cooperatives, and extension services demonstrate significantly more diversified income portfolios. Notably, market access is associated with 28 to 31% lower Ogive index, signaling integration into non-farm activities and value chains. These findings are consistent with evidence that well-functioning markets in Africa (Loison 2015) and bundled infrastructure interventions in Philippines (Hossain et al. 2025) are shown to enhance rural income diversification and raise smallholder income. Cooperative membership exhibited the largest negative marginal effect on specialization in 2013 (36%), highlighting its strong role in promoting income diversification at the time. However, this effect becomes statistically insignificant by 2019, possibly reflecting declining institutional effectiveness.

Participation in MGNREGA is consistently associated with increased diversification, with marginal effects ranging from 27 to 30%, underscoring its significance in facilitating livelihood diversification through public employment programs. Awareness of MSP shows only weak and inconsistent associations with diversification, with marginal effects of 4–5%

Table 2. Tobit estimates of the determinants of income specialization using the Ogive specialization index

Variables	2012–13		2018–19		Pooled	
	Coef.	ME	Coef.	ME	Coef.	ME
Age of household head (years)	0.002***	0.003***	-0.004***	-0.004***	-0.002***	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	0.189***	0.147***	0.010	-0.027	0.071***	0.057***
	(0.032)	(0.026)	(0.024)	(0.022)	(0.020)	(0.017)
Primary education	0.048**	0.036**	0.049***	0.020	0.030**	0.039**
	(0.022)	(0.017)	(0.017)	(0.014)	(0.013)	(0.011)
Secondary education	0.102***	0.111***	0.099***	0.058***	0.083***	0.126***
	(0.023)	(0.018)	(0.024)	(0.021)	(0.016)	(0.014)
Higher secondary and above	0.188***	0.201***	0.204***	0.165***	0.178***	0.195***
	(0.032)	(0.025)	(0.024)	(0.021)	(0.019)	(0.016)
Household size (number of members)	-0.050***	-0.040***	-0.046***	-0.042***	-0.046***	-0.042***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
OBC (1=yes)	-0.060**	-0.051**	-0.089***	-0.062***	-0.077***	-0.062***
	(0.024)	(0.017)	(0.020)	(0.016)	(0.015)	(0.012)
SC/ST (1=yes)	-0.043	-0.095***	-0.052**	-0.080**	-0.058***	-0.067***
	(0.027)	(0.019)	(0.022)	(0.017)	(0.016)	(0.013)
Marginal farmer (2.47 acres)	-0.043*	-0.007	0.063***	0.097***	0.015	0.034***
	(0.025)	(0.020)	(0.018)	(0.016)	(0.014)	(0.012)
Owned land size (acres)	0.019***	0.011***	-0.003	-0.004	0.013***	0.007***
	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.001)
Share irrigated land (%)	0.002***	0.002***	-0.000**	0.000**	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	-0.395***	-0.279***	-0.380***	-0.305***	-0.411***	-0.292***
	(0.023)	(0.017)	(0.019)	(0.016)	(0.014)	(0.012)
Access to extension services	-0.143***	-0.112***	-0.107***	-0.076***	-0.131***	-0.103***
	(0.020)	(0.014)	(0.017)	(0.013)	(0.012)	(0.009)
Access to credit	-0.002	0.016	-0.079***	-0.046***	-0.054***	-0.029***
	(0.019)	(0.014)	(0.015)	(0.012)	(0.012)	(0.009)
Farmer cooperative membership	-0.435***	-0.357***	0.008	0.013	-0.242***	-0.193***
	(0.031)	(0.020)	(0.034)	(0.028)	(0.021)	(0.017)
MGNREGA job card holder	-0.252***	-0.233***	-0.222***	-0.245***	-0.274***	-0.225***
	(0.020)	(0.014)	(0.017)	(0.013)	(0.012)	(0.010)
Awareness of MSP	-0.027	-0.012	-0.037**	-0.034**	-0.008	-0.040***
	(0.023)	(0.016)	(0.017)	(0.014)	(0.013)	(0.011)
Exclusive cereals	-0.495***	-0.427***	-0.278***	-0.342***	-0.410***	-0.401***
	(0.027)	(0.018)	(0.022)	(0.016)	(0.016)	(0.012)
Price shock (1=occurred)	0.039**	0.024	0.048***	0.049***	0.012	0.032***
	(0.018)	(0.015)	(0.017)	(0.015)	(0.012)	(0.010)
Yield shock (1=occurred)	0.109***	0.097***	0.182***	0.168***	0.123***	0.096***
	(0.022)	(0.017)	(0.015)	(0.013)	(0.012)	(0.010)
Climate shock (1=occurred)	0.052**	0.050**	0.060***	0.126***	0.085***	0.084***
	(0.021)	(0.015)	(0.017)	(0.013)	(0.013)	(0.010)
Share income from non-agriculture (%)	-0.010***	-0.008***	-0.009***	-0.008***	-0.009***	-0.008***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log of village population	0.011	-0.025***	0.004	-0.007*	0.003	0.048***
	(0.010)	(0.006)	(0.005)	(0.004)	(0.004)	(0.002)
Log of non-farm asset value	-0.038***	-0.031***	-0.046***	-0.052***	-0.044***	-0.037***
	(0.007)	(0.005)	(0.007)	(0.006)	(0.005)	(0.004)
2019 dummy	-	-	-	-	-0.429***	-
					(0.028)	
Constant	5.670***	-	3.407***	-	5.046***	-
	(0.260)		(0.202)		(0.185)	
F value	43.31***		19.53***		22.90***	
Pseudo R^2	0.076		0.058		0.056	
District FE	Yes		Yes		Yes	
Year FE	No		No		Yes	
Observations	34350		44462		78812	

Notes: Robust standard errors in parentheses. ME = marginal effects. Clustered at village level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

when significant. Exclusive cereal cultivation is associated with the highest levels of income diversification, with marginal effects ranging from 39 to 55. While seemingly paradoxical, this pattern suggests that cereal-producing households frequently engage in non-farm employment or other income-generating activities to stabilize livelihoods. The consistently negative and statistically significant coefficients across model specifications indicate that these households are not income-specialized, but instead diversify beyond agriculture.

Exposure to shocks (particularly yield and climate shocks) is positively and significantly associated with the OSI, indicating a shift toward greater specialization and reduced income diversification among affected households. Yield shocks raise the index by 11 to 19%, while climate shocks increase it by 6 to 14%, suggesting greater reliance on fewer income sources and limited adaptive capacity. A higher share of non-agricultural income is associated with lower specialization, with a marginal effect of approximately 1%, indicating that non-farm income plays a critical role in broadening livelihood strategies. Similarly, a 1% increase in non-farm asset value leads to a 4% to 6% reduction in the specialization index, underscoring the role of capital investment in facilitating income diversification. The effect of village population varies by context: positive in 2013 (3%) but negative in the pooled model (6%), potentially reflecting evolving rural labor market dynamics or heterogeneity in economic opportunities across villages over time.

4.3. Estimates from the Baseline Fixed Effects Specification

Table 3 presents fixed effects estimates of the determinants of MPCI and MPCE. As the OSI coefficient lacks direct interpretability, marginal effects are used to assess the welfare implications of income specialization. Results indicate a statistically significant reduction in MPCI, ranging from 12 to 14%, alongside a modest increase in MPCE of 0.4% to 0.7%. Robustness checks using total monthly household income and consumption expenditure as alternative outcomes yield consistent estimates: a 13% to 14% decline in income and a 0.4% rise in consumption (Table A3). These results underscore the trade-offs associated with specialization and highlight the potential welfare gains from diversification. To explore heterogeneity, OSI is interacted with climate shocks. The negative and significant interaction for MPCI suggests that specialization reduces income under adverse climatic conditions, favoring diversification. The absence of a significant effect on MPCE implies the operation of intra-household consumption smoothing mechanisms that buffer consumption despite income fluctuations.

Table 3. Fixed effects estimates from the baseline specification using the Ogive Specialisation Index

Variables	Per capita household income			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-0.113***	-0.123***	-0.125***	0.002	0.006***	0.006***
	(0.006)	(0.006)	(0.004)	(0.003)	(0.002)	(0.002)
OSI × Climate shock	-0.034***	-0.032***	-0.032***	0.006	-0.003	0.003
	(0.010)	(0.009)	(0.007)	(0.004)	(0.003)	(0.002)
Age of household head (years)	0.003***	0.006***	0.005***	0.004***	0.002***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.158***	0.016	-0.056***	0.055***	0.012**	0.036***
	(0.023)	(0.017)	(0.014)	(0.008)	(0.006)	(0.005)
Primary education	0.017	0.072***	0.058***	0.043***	0.049***	0.062***
	(0.014)	(0.011)	(0.009)	(0.006)	(0.004)	(0.004)
Secondary education	0.099***	0.182***	0.152***	0.108***	0.104***	0.120***
	(0.016)	(0.016)	(0.012)	(0.007)	(0.006)	(0.005)
Higher secondary and above	0.403***	0.420***	0.413***	0.237***	0.179***	0.211***
	(0.023)	(0.018)	(0.014)	(0.010)	(0.006)	(0.006)
Household size	-0.094***	-0.101***	-0.095***	-0.073***	-0.063***	-0.068***
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
OBC (1=yes)	0.000	-0.015	-0.009	-0.024***	-0.040***	-0.046***
	(0.019)	(0.015)	(0.012)	(0.008)	(0.006)	(0.005)
SC/ST (1=yes)	0.011	0.006	0.019	-0.086***	-0.088***	-0.098***
	(0.020)	(0.017)	(0.013)	(0.009)	(0.006)	(0.006)
Marginal farmer (1=Yes)	0.029	-0.220***	-0.164***	-0.057***	-0.057***	-0.056***
	(0.020)	(0.013)	(0.010)	(0.009)	(0.004)	(0.004)
Owned land size (acres)	0.049***	0.054***	0.050***	0.014***	0.014***	0.013***
	(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.004***	0.001***	0.002***	0.001***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	0.155***	-0.067***	0.078***	0.027***	0.006	0.009*
	(0.017)	(0.016)	(0.012)	(0.007)	(0.005)	(0.005)
Access to extension services	0.074***	0.048***	0.068***	0.052***	0.015***	0.042***
	(0.015)	(0.014)	(0.010)	(0.007)	(0.005)	(0.004)
Access to credit	0.031**	0.024**	0.031***	0.020***	0.027***	0.028***
	(0.013)	(0.011)	(0.008)	(0.005)	(0.004)	(0.004)
Farmer cooperative membership	0.180***	0.015	0.179***	0.020**	0.011	0.048***
	(0.022)	(0.026)	(0.017)	(0.010)	(0.009)	(0.008)
MGNREGA job card holder	-0.122***	-0.096***	-0.126***	-0.071***	-0.062***	-0.080***
	(0.015)	(0.013)	(0.010)	(0.006)	(0.005)	(0.004)
Awareness of MSP	0.181***	0.141***	0.155***	0.068***	0.053***	0.073***
	(0.017)	(0.013)	(0.011)	(0.007)	(0.005)	(0.005)
Exclusive cereals	-0.209***	-0.271***	-0.291***	-0.005	-0.020***	-0.047***
	(0.020)	(0.019)	(0.014)	(0.008)	(0.006)	(0.006)
Price shock	0.096***	0.171***	0.154***	0.050***	0.041***	0.052***
	(0.012)	(0.011)	(0.008)	(0.005)	(0.004)	(0.003)
Yield shock	-0.283***	-0.193***	-0.190***	-0.005	0.005	0.000
	(0.018)	(0.011)	(0.009)	(0.007)	(0.004)	(0.003)
Climate shock	-0.059*	-0.049*	-0.096***	-0.031**	-0.004	-0.028***
	(0.033)	(0.027)	(0.021)	(0.015)	(0.009)	(0.009)
Constant	7.438***	7.745***	7.599***	7.108***	7.306***	7.210***
	(0.046)	(0.041)	(0.031)	(0.020)	(0.014)	(0.014)
Marginal effects	-0.123***	-0.135***	-0.135***	0.004*	0.005***	0.007***
	(0.005)	(0.005)	(0.004)	(0.002)	(0.001)	(0.001)
F-value	296.3***	303.7***	552.4***	296.4***	360.9***	583.5***
Adjusted R-squared	0.365	0.354	0.322	0.514	0.526	0.462
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses. Clustered at the village level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Household head age is positively associated with both MPCI and MPCE, consistent with experience-related economic gains. Female-headed households earn less than male-headed ones but report higher MPCE, suggesting distinct consumption patterns. Higher educational attainment strongly correlates with increased MPCI and MPCE, in line with human capital theory. While larger households are associated with lower MPCI and MPCE, indicating that as the number of members increases, household resources are more thinly spread, leading to reduced income and consumption per person. SC/ST status shows no significant link to MPCI but is negatively associated with MPCE, pointing to enduring welfare disparities. Marginal farmers experience significantly lower MPCI and MPCE, reflecting structural vulnerabilities.

Productive assets such as land and irrigation access enhance both outcomes. Institutional access (including extension services, credit, and crop markets) positively affects welfare, with extension services showing the strongest effect. Cooperative membership also correlates positively with income and consumption. In contrast, households with MGNREGA job cards report lower MPCI and MPCE, reflecting effective targeting of vulnerable groups. Awareness of minimum support prices (MSP) is associated with higher welfare, while exclusive cereal cultivation correlates with lower outcomes, highlighting the value of diversification. Price shocks raise welfare when output prices outpace input costs, whereas climate shocks reduce both MPCI and MPCE. Yield shocks primarily affect income, indicating that households adjust resources to maintain consumption despite income losses.

4.4. Results from the Front-Door Criterion (FDC) Approach

Table 4 presents estimation results from the Front-door criterion approach implemented within the Seemingly Unrelated Regression (SUR) framework, indicate a negative association between the OSI and both MPCI and MPCE. A one-unit increase in OSI is associated with a 25 to 32% reduction in MPCI and an approximate 1% decline in MPCE, suggesting that income specialization may weaken household economic resilience. Robustness checks using household-level total income and total consumption expenditure (Table A4) confirm these patterns, indicating a 21 to 27% decline in income and a 0.8 to 1.4% reduction in consumption. These findings are consistent with the literature linking diversification to improved welfare outcomes.

The interaction between OSI and climate shocks shows that specialization increases household vulnerability, as reflected in a significant decline in MPCI. Although the OSI and climate shock interaction term is positive for MPCE, the effect is statistically insignif-

Table 4. Estimates from the Front Door Criterion (FDC) model

Variables	Share of non-agriculture income			MPCI			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-5.064***	-4.996***	-5.090***	-0.063***	-0.069***	-0.075***	0.002	0.008***	0.008***
	(0.164)	(0.148)	(0.108)	(0.005)	(0.004)	(0.003)	(0.002)	(0.001)	(0.001)
OSI × Climate shock (1=occurred)	1.780***	2.613***	2.293***	-0.052***	-0.061***	-0.054***	0.006	-0.004*	0.002
	(0.284)	(0.252)	(0.188)	(0.009)	(0.007)	(0.006)	(0.004)	(0.002)	(0.002)
Share of non-agriculture income (%)	-	-	-	0.010***	0.011***	0.010***	-0.000	0.000***	0.000***
				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age of household head (years)	-0.093***	0.056***	-0.008	0.004***	0.006***	0.005***	0.004***	0.002***	0.003***
	(0.014)	(0.012)	(0.009)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-5.395***	3.128***	0.112	-0.105***	-0.018	-0.057***	0.055***	0.011**	0.036***
	(0.675)	(0.564)	(0.441)	(0.020)	(0.014)	(0.012)	(0.008)	(0.005)	(0.005)
Primary education	-0.974**	1.353***	0.199	0.026**	0.058***	0.056***	0.043***	0.048***	0.062***
	(0.444)	(0.365)	(0.285)	(0.013)	(0.010)	(0.008)	(0.006)	(0.003)	(0.003)
Secondary education	0.385	3.782***	1.795***	0.095***	0.141***	0.134***	0.108***	0.102***	0.120***
	(0.466)	(0.524)	(0.348)	(0.014)	(0.014)	(0.010)	(0.006)	(0.005)	(0.004)
Higher secondary and above	9.952***	11.126***	10.453***	0.304***	0.300***	0.311***	0.237***	0.174***	0.207***
	(0.683)	(0.549)	(0.430)	(0.020)	(0.014)	(0.012)	(0.009)	(0.005)	(0.005)
Household size	1.586***	1.836***	1.659***	-0.109***	-0.121***	-0.111***	-0.073***	-0.064***	-0.069***
	(0.067)	(0.068)	(0.048)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
OBC (1=yes)	1.752***	-0.145	0.529*	-0.017	-0.013	-0.014	-0.024***	-0.040***	-0.046***
	(0.487)	(0.440)	(0.318)	(0.014)	(0.012)	(0.009)	(0.006)	(0.004)	(0.004)
SC/ST (1=yes)	6.943***	6.039***	6.119***	-0.058***	-0.059***	-0.041***	-0.086***	-0.091***	-0.100***
	(0.548)	(0.485)	(0.351)	(0.016)	(0.012)	(0.010)	(0.007)	(0.005)	(0.004)
Marginal farmer (1=yes)	5.128***	13.301***	10.792***	-0.022	-0.364***	-0.270***	-0.057***	-0.063***	-0.059***
	(0.544)	(0.400)	(0.301)	(0.018)	(0.011)	(0.009)	(0.007)	(0.004)	(0.004)
Owned land size (acres)	-0.526***	-0.938***	-0.613***	0.054***	0.064***	0.056***	0.014***	0.014***	0.013***
	(0.052)	(0.071)	(0.041)	(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Share of irrigated land (%)	-0.062***	-0.099***	-0.075***	0.005***	0.002***	0.003***	0.001***	0.000***	0.000***
	(0.005)	(0.005)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	-15.743***	-12.172***	-15.209***	0.311***	0.065***	0.227***	0.027***	0.012***	0.014***
	(0.491)	(0.454)	(0.325)	(0.014)	(0.012)	(0.009)	(0.006)	(0.004)	(0.004)
Access to extension services	-2.767***	-2.307***	-2.191***	0.101***	0.073***	0.090***	0.052***	0.016***	0.043***
	(0.410)	(0.372)	(0.258)	(0.012)	(0.010)	(0.007)	(0.005)	(0.004)	(0.003)
Access to formal credit	1.185***	-0.305	0.791***	0.019*	0.028***	0.023***	0.020***	0.027***	0.028***
	(0.385)	(0.335)	(0.252)	(0.011)	(0.009)	(0.007)	(0.005)	(0.003)	(0.003)
Farmer cooperative membership	-8.031***	-2.395***	-4.564***	0.259***	0.041**	0.224***	0.020**	0.012	0.050***
	(0.599)	(0.758)	(0.439)	(0.018)	(0.021)	(0.013)	(0.009)	(0.008)	(0.006)
MGNREGA job card holder	1.222***	-0.364	1.063***	-0.134***	-0.092***	-0.136***	-0.071***	-0.062***	-0.081***
	(0.430)	(0.381)	(0.278)	(0.012)	(0.010)	(0.007)	(0.005)	(0.004)	(0.003)
Awareness of MSP	-0.230	0.063	0.828***	0.184***	0.140***	0.146***	0.068***	0.053***	0.072***
	(0.462)	(0.393)	(0.290)	(0.014)	(0.010)	(0.008)	(0.006)	(0.004)	(0.003)
Exclusive cereals	-12.089***	-3.724***	-7.781***	-0.089***	-0.231***	-0.215***	-0.005	-0.019***	-0.045***
	(0.560)	(0.500)	(0.356)	(0.017)	(0.014)	(0.010)	(0.007)	(0.005)	(0.004)
Price shock	-0.793**	-4.069***	-3.302***	0.104***	0.215***	0.187***	0.050***	0.042***	0.053***
	(0.373)	(0.368)	(0.261)	(0.011)	(0.010)	(0.007)	(0.005)	(0.004)	(0.003)
Yield shock	7.392***	7.651***	6.130***	-0.357***	-0.276***	-0.251***	-0.005	0.001	-0.002
	(0.479)	(0.340)	(0.263)	(0.014)	(0.009)	(0.007)	(0.006)	(0.003)	(0.003)
Climate shock	-4.024***	-5.088***	-3.773***	-0.019	0.006	-0.058***	-0.031**	-0.002	-0.027***
	(0.967)	(0.756)	(0.588)	(0.028)	(0.021)	(0.017)	(0.013)	(0.008)	(0.007)
2019 dummy	-	-	8.614***	-	-	-0.019**	-	-	0.142***
			(0.270)			(0.008)			(0.003)
Constant	99.836***	31.272***	65.767***	6.584***	7.588***	7.141***	7.128***	7.586***	7.242***
	(4.413)	(4.739)	(4.404)	(0.144)	(0.128)	(0.111)	(0.078)	(0.065)	(0.054)
Treatment effects	–	–	–	-0.050***	-0.054***	-0.050***	0.000^{NS}	-0.002***	-0.002***
				(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Marginal effects	–	–	–	-0.252***	-0.319***	-0.277***	0.000^{NS}	-0.012***	-0.009***
				(0.005)	(0.004)	(0.003)	(0.002)	(0.001)	(0.001)
F Value	54.44***	60.39***	88.82***	41.70***	53.71***	71.52***	59.36***	76.34***	95.06***
Adjusted R-squared	0.355	0.340	0.310	0.432	0.448	0.399	0.514	0.527	0.462
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812	34350	44462	78812

Note: Robust standard errors are in parentheses, clustered at the village level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

icant. For 2018–19, the direct effect of OSI on MPCE is positive, yet the interaction with climate shocks remains negative. Taken together, the results underscore the stabilizing role of income diversification in the face of climate-related risks.

Marginal effects estimated using the front-door criterion (25 to 32%) are 2 to 2.5 times higher than fixed effects estimates (12 to 14%), indicating a stronger causal influence of income diversification on MPCI when accounting for mediation through non-farm income share. While fixed effects address time-invariant heterogeneity, they cannot fully resolve endogeneity from indirect pathways. The front-door approach leverages the mediator to satisfy identification assumptions and reduce bias. Results suggest that diversification raises MPCI largely via increased non-farm income, an effect downward-biased in fixed effects models due to unobserved confounding or selection, introducing omitted variable bias. These findings underscore the importance of modeling mediation to capture the full gains to diversification.

4.5. Results from the Two-Stage Least square (2SLS) Approach

To address endogeneity and strengthen causal inference, income diversification effects are estimated using two-stage least squares (2SLS) and heteroskedasticity-robust GMM (Table 5). Findings indicate that higher income concentration (i.e., lower diversification) significantly reduces MPCI by 56 to 63% across 2012–13, 2018–19, and pooled samples, while MPCE declines by 7 to 10%. Figure 3 illustrates the marginal effects of MPCI and MPCE across varying levels of the OSI. The results indicate a linear negative relationship, wherein higher OSI values are associated with declines in both MPCI and MPCE. Robustness checks using total household income and consumption expenditure reported consistent results, showing a 47 to 53% decline in income and a 6 to 9% drop in consumption (Table A5 and Figure A1).

A positive and significant interaction between OSI and climate shocks indicates that diversification's welfare benefits diminish under climate shock, likely because climate shocks simultaneously disrupt both agricultural income and non-farm employment opportunities. This reversal underscores the importance of situating diversification strategies within climate risk contexts. Our findings suggest that policy interventions promoting diversification should be sensitive to climate variability, as its effectiveness as a risk mitigation tool varies between normal and shock-affected periods.

Older household heads exhibited significantly higher MPCI and MPCE, suggesting welfare gains linked to experience or better risk management. Female-headed house-

Table 5. Two-Stage Least Squares estimates using the Ogive specialisation index as the endogenous variable

Variables	Per capita household income			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-1.120***	-1.460***	-1.305***	-0.134**	-0.236***	-0.202***
	(0.177)	(0.239)	(0.140)	(0.056)	(0.057)	(0.042)
OSI × Climate shock	0.905***	1.234***	1.079***	0.133**	0.227***	0.199***
	(0.165)	(0.226)	(0.132)	(0.053)	(0.054)	(0.040)
Age of household head (years)	0.005***	0.003***	0.004***	0.004***	0.002***	0.003***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.015	-0.021	-0.019	0.074***	0.006	0.043***
	(0.039)	(0.030)	(0.022)	(0.012)	(0.007)	(0.006)
Primary education	0.036*	0.092***	0.066***	0.045***	0.052***	0.063***
	(0.020)	(0.020)	(0.014)	(0.006)	(0.005)	(0.004)
Secondary education	0.153***	0.216***	0.191***	0.116***	0.110***	0.127***
	(0.024)	(0.029)	(0.019)	(0.007)	(0.007)	(0.006)
Higher secondary and above	0.476***	0.484***	0.469***	0.246***	0.191***	0.221***
	(0.034)	(0.031)	(0.023)	(0.011)	(0.008)	(0.007)
Household size (number)	-0.128***	-0.148***	-0.135***	-0.078***	-0.071***	-0.075***
	(0.007)	(0.009)	(0.005)	(0.002)	(0.002)	(0.002)
OBC (1 = yes)	-0.035	-0.061**	-0.041**	-0.029***	-0.048***	-0.051***
	(0.026)	(0.027)	(0.019)	(0.008)	(0.007)	(0.006)
SC/ST (1 = yes)	-0.052*	-0.034	-0.024	-0.094***	-0.096***	-0.106***
	(0.030)	(0.029)	(0.021)	(0.010)	(0.008)	(0.007)
Marginal farmer (1=Yes)	-0.037	-0.293***	-0.257***	-0.066***	-0.071***	-0.073***
	(0.030)	(0.025)	(0.019)	(0.010)	(0.006)	(0.006)
Owned land size (acres)	0.063***	0.061***	0.064***	0.016***	0.015***	0.015***
	(0.004)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.006***	0.001*	0.003***	0.001***	0.000*	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	-0.011	-0.335***	-0.156***	0.005	-0.042***	-0.032***
	(0.037)	(0.055)	(0.033)	(0.012)	(0.013)	(0.010)
Access to extension services	0.011	-0.010	-0.004	0.043***	0.004	0.029***
	(0.024)	(0.025)	(0.018)	(0.008)	(0.006)	(0.006)
Access to formal credit	0.039**	-0.048**	-0.014	0.021***	0.014**	0.020***
	(0.019)	(0.022)	(0.014)	(0.006)	(0.006)	(0.004)
Farmer cooperative membership	0.003	0.070*	0.067**	-0.004	0.022*	0.031***
	(0.044)	(0.042)	(0.029)	(0.014)	(0.011)	(0.010)
MGNREGA job card holder	-0.268***	-0.269***	-0.312***	-0.091***	-0.094***	-0.113***
	(0.032)	(0.037)	(0.027)	(0.010)	(0.009)	(0.008)
Awareness of MSP	0.149***	0.110***	0.146***	0.064***	0.048***	0.071***
	(0.024)	(0.023)	(0.016)	(0.008)	(0.006)	(0.005)
Exclusive cereals (dummy)	-0.507***	-0.542***	-0.609***	-0.046**	-0.069***	-0.102***
	(0.060)	(0.057)	(0.043)	(0.019)	(0.014)	(0.013)
Price shock	0.132***	0.241***	0.190***	0.055***	0.053***	0.058***
	(0.019)	(0.024)	(0.014)	(0.006)	(0.006)	(0.004)
Yield shock	-0.297***	-0.125***	-0.164***	-0.008	0.017***	0.006
	(0.024)	(0.023)	(0.014)	(0.007)	(0.006)	(0.004)
Climate shock	-3.232***	-3.882***	-3.616***	-0.459***	-0.699***	-0.648***
	(0.558)	(0.684)	(0.417)	(0.177)	(0.163)	(0.126)
2019 dummy	-	-	-0.296***	-	-	0.081***
	-	-	(0.046)	-	-	(0.014)
Marginal effects	-0.561***	-0.630***	-0.602***	-0.066**	-0.100***	-0.092***
	(0.089)	(0.103)	(0.065)	(0.028)	(0.024)	(0.019)
F Value	140.2***	100.6***	225.5***	271.56***	252.16***	494.36***
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Notes: Robust standard errors in parentheses, clustered at the village level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

holds reported lower income but higher consumption, pointing to possible consumption smoothing. Marginal farmers faced lower MPCI and MPCE, reflecting land constraints. Land ownership and irrigation access positively affect both income and consumption, highlighting asset-based welfare gains. Extension services and formal credit are more strongly associated with MPCE than income, indicating their consumption-stabilizing role. Exclusive cereal cultivation is linked to lower welfare, suggesting welfare costs of specialization. Climate shocks negatively affect both MPCI and MPCE, while price shocks are positively associated, possibly reflecting favorable price movements.

To examine nonlinearity, we included a squared term in both the MPCI and MPCE models and identify turning points between 3.278 and 3.497, suggesting welfare peaks at moderate-to-high specialization levels (Table A6). Even with the squared term, OSI maintains a negative linear association with both MPCI and MPCE (Figure A2).

After addressing endogeneity, 2SLS estimates remained consistent with fixed effects and front-door models, strengthening confidence in the identification strategy and the robustness of the core findings. The stronger marginal effects suggest that instrumented diversification is causally linked to improvements in MPCI and MPCE, reinforcing prior evidence on the welfare-enhancing role of diversification.

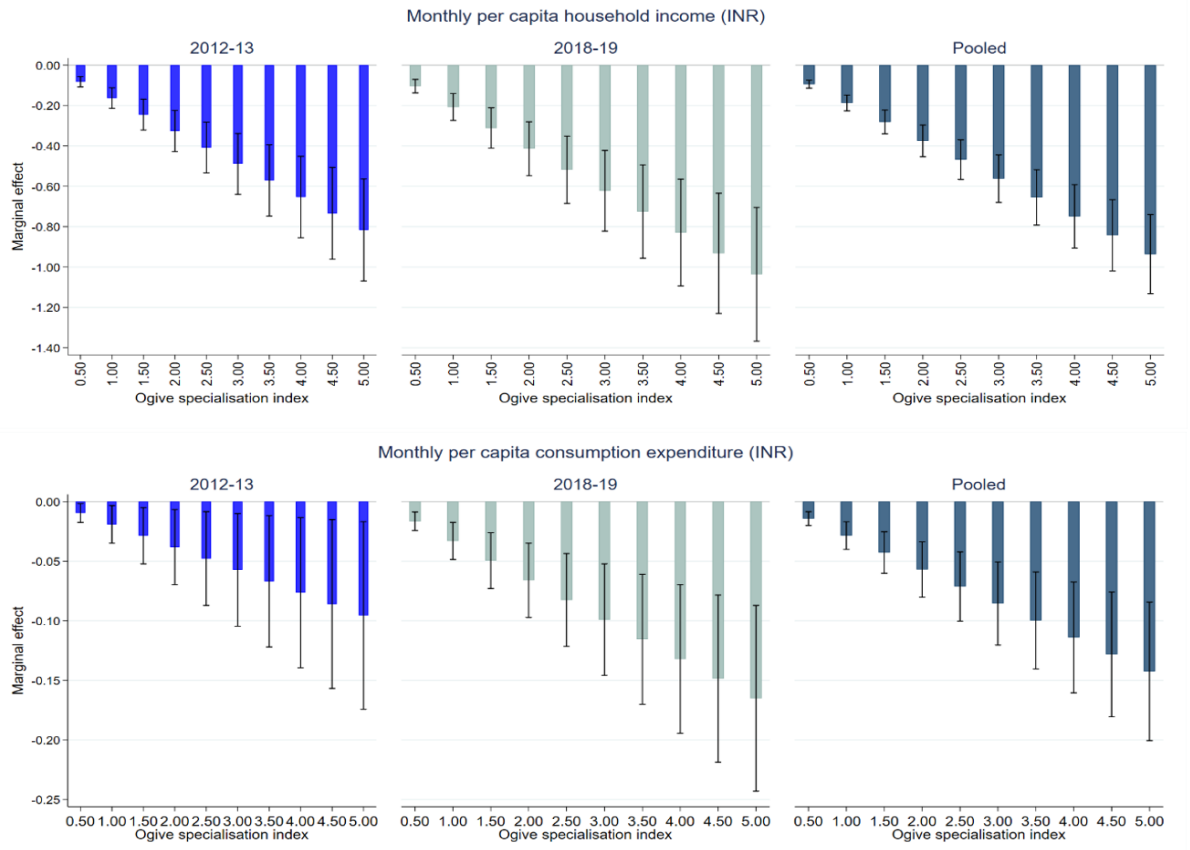

Figure 3. Marginal effects from the 2SLS model using the Ogive specialization index

4.6. 2SLS using alternative diversification measure

To assess the robustness of the results, the SDI is employed in place of the OSI, using the same set of control variables. Two-stage least squares (2SLS) estimates reported in Table 6 indicate a significant positive association between income diversification and household welfare. The marginal effects on MPCI range from 26% in 2012–13 to 41% in 2018–19, with a pooled estimate of 33%. For MPCE, the corresponding effects are 3% and 7%, respectively, with a pooled effect of 5%. The larger effects in the more recent period suggest that diversification has grown increasingly important for household resilience amid rising climate shocks. Figure 4 further illustrates a positive linear relationship between SDI and both MPCI and MPCE. Supplementary results for total household income and consumption expenditure are reported in Table A7 and Figure A3.

Compared to IV estimates using the OSI (which yield negative and larger-magnitude effects) the SDI produces smaller, yet positive and statistically significant coefficients. This contrast reflects differences in index construction, OSI captures the concentration of income sources, emphasizing dominance, while SDI reflects income evenness across activities. The consistent direction and significance of results across both specifications reinforce the robustness of the core finding, diversification improves household welfare. Differences in coefficient magnitude underscore each index's sensitivity to different dimensions of income distribution. This dual-index estimation enhances empirical credibility, offering complementary perspectives and validating the positive causal relationship between income diversification and welfare outcomes.

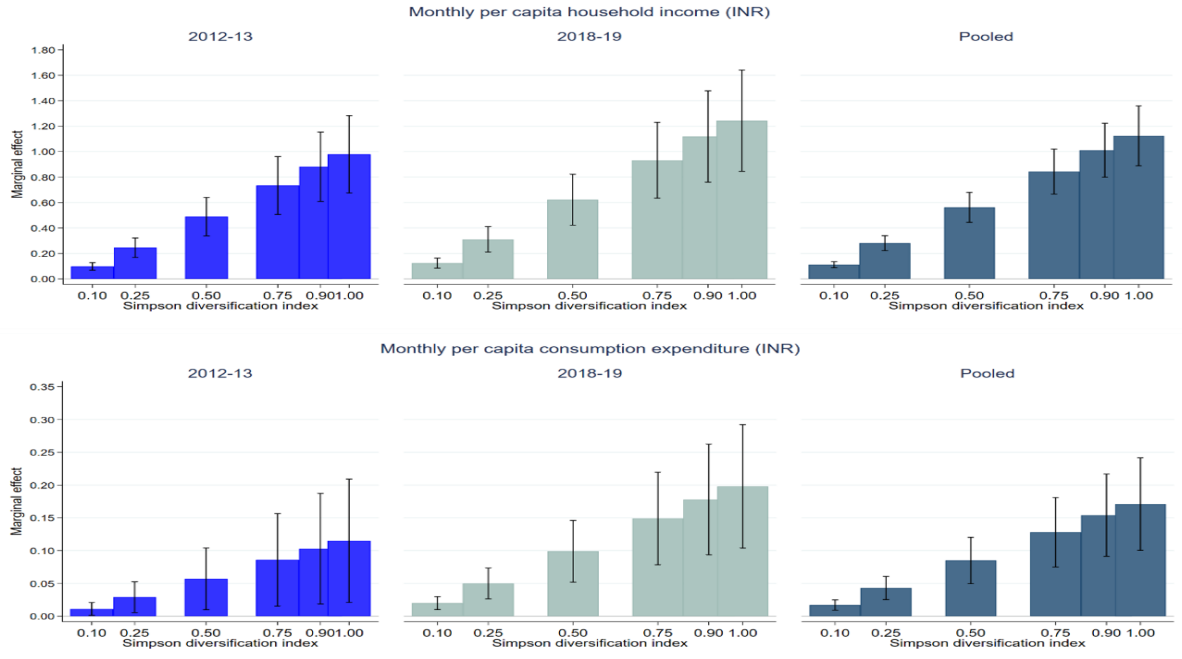

Figure 4. Marginal effects from the 2SLS model using the Simpson diversification index

Table 6. Robustness Check: Two-Stage Least Squares Estimates with Simpson Diversification Index as the Endogenous Variable

Variables	Per capita household income			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Simpson diversification index (SDI)	6.720***	8.763***	7.830***	0.803**	1.419***	1.213***
	(1.062)	(1.432)	(0.839)	(0.338)	(0.342)	(0.252)
SDI × Climate shock (1 = occurred)	-5.430***	-7.401***	-6.475***	-0.795**	-1.359***	-1.193***
	(0.992)	(1.357)	(0.791)	(0.315)	(0.324)	(0.238)
Age of household head (years)	0.005***	0.003***	0.004***	0.004***	0.002***	0.003***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.015	-0.021	-0.019	0.074***	0.006	0.043***
	(0.039)	(0.030)	(0.022)	(0.012)	(0.007)	(0.006)
Primary education	0.036*	0.092***	0.066***	0.045***	0.052***	0.063***
	(0.020)	(0.020)	(0.014)	(0.006)	(0.005)	(0.004)
Secondary education	0.153***	0.216***	0.191***	0.116***	0.110***	0.127***
	(0.024)	(0.029)	(0.019)	(0.007)	(0.007)	(0.006)
Higher secondary and above	0.476***	0.484***	0.469***	0.246***	0.191***	0.221***
	(0.034)	(0.031)	(0.023)	(0.011)	(0.008)	(0.007)
Household size (number)	-0.128***	-0.148***	-0.135***	-0.078***	-0.071***	-0.075***
	(0.007)	(0.009)	(0.005)	(0.002)	(0.002)	(0.002)
OBC (1 = yes)	-0.035	-0.061**	-0.041**	-0.029***	-0.048***	-0.051***
	(0.026)	(0.027)	(0.019)	(0.008)	(0.007)	(0.006)
SC/ST (1 = yes)	-0.052*	-0.034	-0.024	-0.094***	-0.096***	-0.106***
	(0.030)	(0.029)	(0.021)	(0.010)	(0.008)	(0.007)
Marginal farmer (1 = yes)	-0.037	-0.293***	-0.257***	-0.066***	-0.071***	-0.073***
	(0.030)	(0.025)	(0.019)	(0.010)	(0.006)	(0.006)
Owned land size (acres)	0.063***	0.061***	0.064***	0.016***	0.015***	0.015***
	(0.004)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.006***	0.001*	0.003***	0.001***	0.000*	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets (dummy)	-0.011	-0.335***	-0.156***	0.005	-0.042***	-0.032***
	(0.037)	(0.055)	(0.033)	(0.012)	(0.013)	(0.010)
Access to extension services (dummy)	0.011	-0.010	-0.004	0.043***	0.004	0.029***
	(0.024)	(0.025)	(0.018)	(0.008)	(0.006)	(0.006)
Access to credit (dummy)	0.039**	-0.048**	-0.014	0.021***	0.014**	0.020***
	(0.019)	(0.022)	(0.014)	(0.006)	(0.006)	(0.004)
Farmer cooperative membership (dummy)	0.003	0.070*	0.067**	-0.004	0.022*	0.031***
	(0.044)	(0.042)	(0.029)	(0.014)	(0.011)	(0.010)
MGNREGA job card holder (dummy)	-0.268***	-0.269***	-0.312***	-0.091***	-0.094***	-0.113***
	(0.032)	(0.037)	(0.027)	(0.010)	(0.009)	(0.008)
Awareness of MSP (dummy)	0.149***	0.110***	0.146***	0.064***	0.048***	0.071***
	(0.024)	(0.023)	(0.016)	(0.008)	(0.006)	(0.005)
Exclusive cereals (dummy)	-0.507***	-0.542***	-0.609***	-0.046**	-0.069***	-0.102***
	(0.060)	(0.057)	(0.043)	(0.019)	(0.014)	(0.013)
Price shock (1 = occurred)	0.132***	0.241***	0.190***	0.055***	0.053***	0.058***
	(0.019)	(0.024)	(0.014)	(0.006)	(0.006)	(0.004)
Yield shock (1 = occurred)	-0.297***	-0.125***	-0.164***	-0.008	0.017***	0.006
	(0.024)	(0.023)	(0.014)	(0.007)	(0.006)	(0.004)
Climate shock (1 = occurred)	1.292***	2.286***	1.780***	0.203**	0.434***	0.346***
	(0.269)	(0.448)	(0.242)	(0.086)	(0.107)	(0.073)
2019 dummy	-	-	-0.296***	-	-	0.081***
	-	-	(0.046)	-	-	(0.014)
Marginal effects	0.255***	0.406***	0.334***	0.030**	0.065***	0.051***
	(0.040)	(0.066)	(0.036)	(0.013)	(0.016)	(0.011)
F Value	140.2***	100.6***	225.5***	271.56***	252.16***	494.36***
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses, clustered at village level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

5. Discussion

Marginalized households (SC/ST and marginal landholders) and households with greater MGNREGA participation are more likely to be partially diversified, based on descriptive statistics. Tobit estimates showed that SC/ST status and MGNREGA involvement are positively associated with diversification, underscoring public employment's role in facilitating livelihood transitions. Marginal landholders in India exhibit income specialization, contrasting with the diversification strategies commonly observed among smallholders in developed country contexts. In the USA (Khanal and Mishra, 2014) and Italy (Grilli et al., 2025), where small farms diversify to mitigate income risk. Indian marginal farmers concentrate on a single high-return activity, shaped by structural constraints including limited access to credit, education, markets, and institutional support. Social protection enhances human capital and promotes livelihood diversification through liquidity effects, despite limited cross-country evidence (Kangasniemi et al., 2025). By comparison, evidence from Egypt (Sattar et al., 2024) showed that links between farm size and livelihood diversification are context-specific, with low-income farmers remaining reliant on agriculture.

Our finding showed that land ownership was significantly associated with specialization in 2012–13 and in pooled estimates, this relationship became statistically insignificant by 2018–19, indicating a shift away from land-dependence. In contrast, non-agricultural income shares remain negatively associated with specialization, underscoring the central role of non-farm earnings in facilitating livelihood diversification. Similarly, higher non-farm asset values are linked to reduced specialization, suggesting that capital accumulation enables households to pursue a broader set of income-generating activities. These findings are consistent with earlier studies that identify land access, education, asset ownership, and proximity to urban centers as key enablers of entry into high-return rural non-farm employment (Barrett et al. 2001; Reardon et al. 2001; De Janvry and Sadoulet, 2001; Davis et al. 2010; Haggblade et al. 2007; Hammond et al. 2023). In Nepal, access to land, skills, and assets is vital for diversifying into non-farm activities (Gautam and Andersen 2016), while in the Indian Himalayas, diversification is driven more by labor availability, livestock holdings, and market access than land size (Shukla et al. 2019). In the U.S., education, age, financial status, and farm location are key drivers (Khanal and Mishra 2014). In Ethiopia, secure land tenure and cooperative membership facilitate non-farm participation (Kassie et al. 2017). Constraints such as limited capital inhibit diversification in Mali (Abdulai & Crole-Rees 2001), while wealthier Kenyan households use land as collateral to access more lucrative non-farm sources (Muthini et al. 2025). In Bangladesh, non-farm income alleviates liquidity constraints and enhances farm input

use (Mondal et al. 2021). Education plays a pivotal role in enabling diversification, as shown by recent evidence from Paraguay (Bogado et al. 2024).

Tri-econometric models show that the welfare gains of diversification remain limited under climate shocks. Exposure to climate shocks is positively associated with specialization and reduced income diversification among affected households. These findings align with prior evidence that drought reduces livelihood diversity and that diversification offers limited protection against food insecurity in Africa (Musumba et al., 2022) and Nigeria (Dedehouanou & McPeak, 2020). other studies found that diversification facilitates recovery from shocks without distress, thereby enhancing adaptive capacity (Poffenbarger et al., 2017; Carr, 2020). However, study from India suggest that combining crop and livestock activities may enhance resilience to climate shocks under certain conditions (Das et al., 2025).

The OSI interaction with climate shocks positive in the 2SLS framework, indicating that, when endogeneity is addressed, specialization may be more protective than reactive diversification. While households often diversify into non-farm activities during shocks, such strategies are frequently constrained and yield limited returns, particularly under climate shocks where many income sources are simultaneously disrupted. Diversification lowers individual risk but offers limited protection against systemic covariate shocks, as nonfarm opportunities also decline during widespread adverse shocks (Barrett et al., 2001 and Dercon, 2002), consistent with our findings. The declining marginal gains highlight the need to enhance the quality and resilience of non-farm income sources, rather than relying solely on diversification as a shock-mitigation strategy. Rainfall and temperature shocks consistently alter rural labor allocation across Asian contexts, though effects differ by country. In India, rainfall shocks increase reliance on farm employment while suppressing non-farm participation, particularly for women and marginalized groups (Darko et al. 2025). Climatic variability drives income diversification, a strategy adopted by 64% of rice farming households in Philippines (Pede et al. 2024). Extreme rainfall reduces agricultural productivity and employment, triggering shifts toward non-agricultural work and increased migration in China (Wang 2024).

Marginal effects from the front-door approach are 2 to 2.5 times larger than fixed effects estimates, indicating a stronger causal impact of income diversification on MPCI through non-farm income share. The 2SLS estimates align closely with both strategies, underscoring the importance of addressing endogeneity. Under 2SLS, income diversification raises MPCI by 56 to 63% and MPCE by 7–10%, highlighting its relevance for rural welfare outcomes. Our results align with a growing body of empirical evidence linking income diversification to household welfare outcomes. In India, access to non-farm income

improves consumption and reduces poverty (Lanjouw and Murgai, 2009), particularly among the poorest households (Minithra, 2021). However, the distributional effects are mixed: while wage and livestock income reduce inequality, income from cultivation and off-farm self-employment tends to widen disparities across farm sizes (Areef and Radha 2022). Supporting the agriculture-livestock-forestry nexus aids rural diversification and sustainability (Mishra et al., 2024).

In Africa, engagement in rural non-farm activities reduces poverty by mitigating household vulnerability and facilitating consumption smoothing, thereby strengthening resilience (Start, 2001; Ellis and Freeman, 2004). Awareness for nonfarm enterprises, fostering inclusive growth and poverty reduction in rural households in Cameroon (Wirba et al., 2025). In Ethiopia, participation in both farming and off-farming activities significantly improves food security and nutrition outcomes (Haile et al., 2025; Bitana et al., 2023), while off-farm diversification specifically has shown greater effectiveness in enhancing both smallholder welfare and nutrition compared to farm or mixed strategies (Sisay 2024). In Nigeria, diversification is positively influenced by household wealth, though with diminishing returns, contributing to food security and resilience (Dedehouanou and McPeak, 2020). In Bangladesh, diversification plays a central role in increasing income and resilience, promoting sustainable rural livelihoods (Tasnim et al. 2025). Evidence from China suggests that mixed and pure non-farm engagement increases household income, improving rural well-being through higher earnings (Ma et al. 2025). Rural-to-urban migration has made non-farm employment central to income diversification and livelihood strategies in China (Hu et al., 2025). However, diversification benefits are gendered, with male-headed households experiencing greater welfare gains than female-headed ones in Uganda (Khan and Morrissey 2023). These findings underscore the importance of context-specific policies in designing effective rural livelihood strategies.

We plotted the marginal effects of MPCI and MPCE across varying levels of the OSI. The results indicate a consistently negative linear relationship, higher OSI values are associated with lower MPCI and MPCE, even with the inclusion of a squared term. Existing literature notes that diversification effects vary by context and measurement, positive relationships are common in Africa, negative in Latin America, and mixed in Asia (FAO 1998; Reardon 1997; Reardon et al. 2000; Loison 2015). However, U-shaped patterns in Asia and Latin America reflect broader opportunities for both poor and asset-rich households (FAO, 1998; Reardon & Taylor, 1996; Reardon et al., 2000). At low-income levels, rural households engage in diversification primarily for survival. As incomes rise, diversification expands to manage risk and enhance earnings. The study finds a consistently positive linear relationship between diversification and income, providing no

evidence of diminishing returns. This pattern offers no evidence of diminishing returns, indicating that even highly diversified households experience income gains, an insight with important implications for rural livelihood policy design.

6. Conclusions

This study examines the determinants of income diversification and its causal pathways in shaping household welfare outcomes in India. Using pooled panel data of agricultural households, we assess whether non-farm income serves as a key driver of welfare gains, or if other income sources also play significant roles. Estimates from the FDC approach reveal significant negative effects indicating that greater reliance on specialized income sources may reduce welfare outcomes. The magnitude of this relationship intensifies under a 2SLS framework highlighting the importance of addressing endogeneity. Analysis across three estimation strategies (Fixed Effects, FDC, and 2SLS) shows that higher levels of income specialization are negatively associated with both MPCI and MPCE. These results underscore the significance of robust identification strategies and support the hypothesis that income diversification enhances household welfare by mitigating risk.

Despite favouring wealthier households, income diversification remains a crucial safety net for marginal farmers, underscoring the need for inclusive policies that lower entry barriers and expand access among the smallholders in India. Effective rural transformation requires integrated policies that promote non-farm employment through investment in education, improved credit access, inclusive non-agricultural employment, and the removal of structural barriers facing women and marginalized groups (Davis et al. 2010; Darko et al. 2025; Lowder et al. 2025; Mutsami et al., 2025). Targeted climate adaptation in India requires region-specific policies that prioritize income diversification and smallholder welfare. Strengthening employment programs (like MGNREGA) and directing investments toward local farming systems are essential to support smallholders and foster resilient, inclusive rural transformation.

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Appendix

Table A1. Determinants of the Ogive Specialisation Index: Testing Instrument Exogeneity Using First-Stage Regression

Variables	Dependent: Ogive Specialisation Index (OSI)		
	2012–13	2018–19	Pooled
Log of village population	-0.019**	-0.011*	0.057***
	(0.009)	(0.006)	(0.002)
Log of non-farm asset value purchased (INR)	-0.053***	-0.074***	-0.059***
	(0.006)	(0.007)	(0.005)
Age of household head (years)	0.003***	-0.004***	-0.001**
	(0.001)	(0.001)	(0.000)
Female-headed household (dummy)	0.164***	-0.051**	0.044**
	(0.026)	(0.023)	(0.017)
Primary education	0.040**	0.025	0.042***
	(0.019)	(0.016)	(0.012)
Secondary education	0.107***	0.049**	0.120***
	(0.020)	(0.023)	(0.015)
Higher secondary and above	0.140***	0.112***	0.137***
	(0.027)	(0.023)	(0.018)
Household size (number of members)	-0.045***	-0.047***	-0.047***
	(0.003)	(0.003)	(0.002)
Other Backward Classes (OBC) (1=yes)	-0.045**	-0.045**	-0.051***
	(0.022)	(0.020)	(0.015)
Scheduled Castes or Tribes (SC/ST) (1=yes)	-0.120***	-0.089***	-0.082***
	(0.026)	(0.023)	(0.017)
Marginal farmer household (1=yes)	-0.042*	0.003	-0.042***
	(0.024)	(0.018)	(0.013)
Owned land size (acres)	0.019***	0.005*	0.014***
	(0.002)	(0.003)	(0.002)
Share of irrigated to operational land (%)	0.003***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)
Access to crop markets (dummy)	-0.159***	-0.216***	-0.183***
	(0.022)	(0.020)	(0.015)
Access to extension services (dummy)	-0.099***	-0.087***	-0.102***
	(0.019)	(0.017)	(0.013)
Access to credit (dummy)	-0.007	-0.071***	-0.054***
	(0.017)	(0.015)	(0.011)
Farmer cooperative membership (dummy)	-0.304***	0.007	-0.150***
	(0.029)	(0.034)	(0.023)
MGNREGA job card holder (dummy)	-0.255***	-0.259***	-0.242***
	(0.019)	(0.017)	(0.013)
Awareness of minimum support price (dummy)	0.008	-0.047***	-0.043***
	(0.021)	(0.018)	(0.014)
Exclusive cultivation of cereals (dummy)	-0.318***	-0.280***	-0.314***
	(0.022)	(0.021)	(0.015)
Price shock (1=occurred)	0.035**	0.080***	0.064***
	(0.016)	(0.016)	(0.011)
Yield shock (1=occurred)	0.035*	0.099***	0.037***
	(0.021)	(0.015)	(0.012)
Climate shock (1=occurred)	-0.006	0.077***	0.029**
	(0.020)	(0.018)	(0.013)
Constant	4.289***	4.072***	3.246***
	(0.156)	(0.082)	(0.049)
F Value	71.90***	66.73***	145.03***
Adjusted R-squared	0.064	0.046	0.063
Observations	34350	44462	78812

Notes: Robust standard errors in parentheses. Clustered at village level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A2. Tests for instrument validity used in the analysis

Variables	Per capita total HH income			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Hansen J statistic (overidentification test): Chi-sq (1)	1.558^{NS}	1.718^{NS}	0.757^{NS}	3.281^{NS}	0.919^{NS}	15.936***
Under-identification test (Kleibergen–Paap rk LM statistic)—Chi-sq (2)	53.21***	40.48***	104.31***	53.21***	40.48***	104.31***
Weak identification test (Cragg–Donald Wald F statistic)	38.34***	27.58***	73.45***	38.34***	27.58***	73.45***
Weak identification test (Kleibergen–Paap rk Wald F statistic)	28.16***	21.17***	57.01***	28.16***	21.17***	57.01***
Endogeneity test	60.11***	83.69***	142.12***	6.28***	26.37***	28.85***

Note: *** denotes significance at 1% and NS denotes insignificance at 1%.
Source: Authors' calculations.

Table A3. Fixed effects estimates from the baseline specification using the Ogive specialization index

Variables	Monthly total HH Income			Monthly consumption expenditure		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-0.121***	-0.130***	-0.131***	-0.006**	-0.000	-0.001
	(0.006)	(0.006)	(0.004)	(0.003)	(0.002)	(0.002)
OSI × Climate shock (1=occurred)	-0.034***	-0.032***	-0.032***	0.006	-0.002	0.003
	(0.010)	(0.009)	(0.007)	(0.004)	(0.003)	(0.003)
Age of household head (years)	0.001***	0.004***	0.003***	0.002***	-0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.242***	-0.067***	-0.141***	-0.029***	-0.071***	-0.049***
	(0.023)	(0.017)	(0.014)	(0.009)	(0.007)	(0.006)
Primary education	0.015	0.078***	0.060***	0.041***	0.054***	0.064***
	(0.014)	(0.011)	(0.009)	(0.006)	(0.004)	(0.004)
Secondary education	0.101***	0.190***	0.157***	0.110***	0.112***	0.125***
	(0.016)	(0.016)	(0.012)	(0.007)	(0.006)	(0.005)
Higher secondary and above	0.392***	0.423***	0.410***	0.226***	0.182***	0.207***
	(0.023)	(0.018)	(0.014)	(0.010)	(0.007)	(0.006)
Household size (number)	0.075***	0.090***	0.085***	0.095***	0.128***	0.112***
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
OBC (1=yes)	0.004	-0.010	-0.006	-0.020**	-0.036***	-0.043***
	(0.019)	(0.015)	(0.012)	(0.008)	(0.006)	(0.005)
SC/ST (1=yes)	0.013	0.011	0.021	-0.084***	-0.084***	-0.095***
	(0.020)	(0.017)	(0.013)	(0.009)	(0.007)	(0.006)
Marginal farmer (1=yes)	0.018	-0.227***	-0.174***	-0.068***	-0.065***	-0.065***
	(0.020)	(0.013)	(0.010)	(0.008)	(0.005)	(0.004)
Owned land size (acres)	0.047***	0.051***	0.047***	0.012***	0.011***	0.010***
	(0.002)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.004***	0.001***	0.002***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	0.154***	-0.073***	0.075***	0.027***	0.000	0.006
	(0.017)	(0.016)	(0.012)	(0.007)	(0.006)	(0.005)
Access to extension	0.085***	0.051***	0.075***	0.063***	0.018***	0.048***
	(0.015)	(0.013)	(0.010)	(0.007)	(0.005)	(0.005)
Access to credit	0.049***	0.043***	0.048***	0.038***	0.045***	0.045***
	(0.013)	(0.011)	(0.008)	(0.006)	(0.004)	(0.004)
Farmer cooperative membership	0.186***	0.018	0.184***	0.027***	0.014	0.053***
	(0.022)	(0.026)	(0.017)	(0.010)	(0.010)	(0.008)
MGNREGA job card holder	-0.103***	-0.086***	-0.115***	-0.052***	-0.053***	-0.070***
	(0.015)	(0.013)	(0.010)	(0.006)	(0.005)	(0.004)
Awareness of MSP	0.177***	0.137***	0.151***	0.064***	0.050***	0.069***
	(0.017)	(0.013)	(0.011)	(0.007)	(0.005)	(0.005)
Exclusive cereals	-0.198***	-0.264***	-0.282***	0.006	-0.013**	-0.038***
	(0.020)	(0.019)	(0.014)	(0.008)	(0.007)	(0.006)
Price shock	0.098***	0.167***	0.153***	0.052***	0.037***	0.050***
	(0.012)	(0.011)	(0.008)	(0.005)	(0.004)	(0.004)
Yield shock	-0.288***	-0.193***	-0.190***	-0.010	0.005	0.000
	(0.018)	(0.011)	(0.009)	(0.007)	(0.004)	(0.004)
Climate shock	-0.057*	-0.047*	-0.095***	-0.029*	-0.003	-0.028***
	(0.033)	(0.027)	(0.021)	(0.015)	(0.010)	(0.009)
Constant	8.216***	8.432***	8.334***	7.886***	7.994***	7.945***
	(0.046)	(0.041)	(0.031)	(0.021)	(0.016)	(0.014)
Marginal effects	-0.131***	-0.141***	-0.142***	-0.004**	-0.001	0.000
	(0.005)	(0.005)	(0.004)	(0.002)	(0.001)	(0.001)
F Value	417.9***	419.9***	781.4***	454.5***	698.9***	1002.0***
Adjusted R-squared	0.395	0.377	0.346	0.567	0.625	0.539
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses. Clustered at village level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A4. Estimates from the Front Door Criterion (FDC) model using the Ogive specialization index

Variables	Share of non-agri. income (%)			HH income (log)			cons. expen. (log)		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-5.064***	-4.996***	-5.090***	-0.068***	-0.075***	-0.080***	-0.004	0.003*	0.002
	(0.164)	(0.148)	(0.108)	(0.005)	(0.004)	(0.003)	(0.002)	(0.002)	(0.001)
OSI × Climate shock (1=yes)	1.780***	2.613***	2.293***	-0.052***	-0.061***	-0.055***	0.005	-0.004	0.002
	(0.284)	(0.252)	(0.188)	(0.009)	(0.007)	(0.006)	(0.004)	(0.003)	(0.002)
Share of income from non-agri (%)	–	–	–	0.010***	0.011***	0.010***	0.000***	0.001***	0.001***
				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age of household head (years)	-0.093***	0.056***	-0.008	0.002***	0.003***	0.003***	0.002***	-0.000	0.001***
	(0.014)	(0.012)	(0.009)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed household (1=yes)	-5.395***	3.128***	0.112	-0.186***	-0.101***	-0.142***	-0.027***	-0.073***	-0.049***
	(0.675)	(0.564)	(0.441)	(0.020)	(0.014)	(0.012)	(0.009)	(0.006)	(0.006)
Primary education	-0.974**	1.353***	0.199	0.025**	0.063***	0.058***	0.042***	0.053***	0.064***
	(0.444)	(0.365)	(0.285)	(0.013)	(0.010)	(0.008)	(0.006)	(0.004)	(0.003)
Secondary education	0.385	3.782***	1.795***	0.097***	0.148***	0.139***	0.110***	0.109***	0.124***
	(0.466)	(0.524)	(0.348)	(0.013)	(0.014)	(0.010)	(0.006)	(0.006)	(0.004)
Higher secondary and above	9.952***	11.126***	10.453***	0.289***	0.301***	0.304***	0.222***	0.175***	0.201***
	(0.683)	(0.549)	(0.430)	(0.019)	(0.014)	(0.012)	(0.009)	(0.006)	(0.005)
Household size (number of members)	1.586***	1.836***	1.659***	0.059***	0.070***	0.068***	0.095***	0.126***	0.111***
	(0.067)	(0.068)	(0.048)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Other Backward Classes (OBC) (1 = yes)	1.752***	-0.145	0.529*	-0.014	-0.008	-0.011	-0.021***	-0.036***	-0.044***
	(0.487)	(0.440)	(0.318)	(0.014)	(0.011)	(0.009)	(0.006)	(0.005)	(0.004)
Scheduled Castes or Tribes (SC/ST) (1 = yes)	6.943***	6.039***	6.119***	-0.059***	-0.055***	-0.040***	-0.087***	-0.088***	-0.099***
	(0.548)	(0.485)	(0.351)	(0.015)	(0.012)	(0.009)	(0.007)	(0.005)	(0.004)
Marginal farmer household (1 = yes)	5.128***	13.301***	10.792***	-0.035**	-0.373***	-0.283***	-0.070***	-0.073***	-0.072***
	(0.544)	(0.400)	(0.301)	(0.018)	(0.012)	(0.009)	(0.007)	(0.005)	(0.004)
Owned land size (acres)	-0.526***	-0.938***	-0.613***	0.052***	0.061***	0.054***	0.013***	0.011***	0.011***
	(0.052)	(0.071)	(0.041)	(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Share of irrigated to operational land (%)	-0.062***	-0.099***	-0.075***	0.004***	0.002***	0.003***	0.000***	0.000***	0.000***
	(0.005)	(0.005)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets (dummy)	-15.743***	-12.172***	-15.209***	0.317***	0.061***	0.229***	0.033***	0.007*	0.015***
	(0.491)	(0.454)	(0.325)	(0.014)	(0.012)	(0.009)	(0.006)	(0.004)	(0.004)
Access to extension services (dummy)	-2.767***	-2.307***	-2.191***	0.113***	0.077***	0.097***	0.064***	0.019***	0.050***
	(0.410)	(0.372)	(0.258)	(0.012)	(0.009)	(0.007)	(0.005)	(0.004)	(0.003)
Access to formal credit (dummy)	1.185***	-0.305	0.791***	0.037***	0.046***	0.040***	0.038***	0.046***	0.045***
	(0.385)	(0.335)	(0.252)	(0.011)	(0.009)	(0.007)	(0.005)	(0.004)	(0.003)
Farmer cooperative membership (dummy)	-8.031***	-2.395***	-4.564***	0.269***	0.044**	0.230***	0.030***	0.016*	0.055***
	(0.599)	(0.758)	(0.439)	(0.018)	(0.021)	(0.013)	(0.009)	(0.008)	(0.006)
MGNREGA job card holder (dummy)	1.222***	-0.364	1.063***	-0.116***	-0.082***	-0.126***	-0.053***	-0.053***	-0.070***
	(0.430)	(0.381)	(0.278)	(0.012)	(0.010)	(0.007)	(0.005)	(0.004)	(0.003)
Awareness of minimum support price (dummy)	-0.230	0.063	0.828***	0.180***	0.137***	0.142***	0.064***	0.050***	0.068***
	(0.462)	(0.393)	(0.290)	(0.013)	(0.010)	(0.008)	(0.006)	(0.004)	(0.004)
Exclusive cultivation of cereals (dummy)	-12.089***	-3.724***	-7.781***	-0.073***	-0.223***	-0.204***	0.011*	-0.011**	-0.034***
	(0.560)	(0.500)	(0.356)	(0.017)	(0.014)	(0.010)	(0.007)	(0.005)	(0.004)
Price shock (1 = occurred)	-0.793**	-4.069***	-3.302***	0.106***	0.212***	0.186***	0.052***	0.039***	0.052***
	(0.373)	(0.368)	(0.261)	(0.011)	(0.010)	(0.007)	(0.005)	(0.004)	(0.003)
Yield shock (1 = occurred)	7.392***	7.651***	6.130***	-0.365***	-0.277***	-0.252***	-0.013**	0.000	-0.003
	(0.479)	(0.340)	(0.263)	(0.014)	(0.009)	(0.007)	(0.006)	(0.004)	(0.003)
Climate shock (1 = occurred)	-4.024***	-5.088***	-3.773***	-0.015	0.009	-0.057***	-0.027**	0.000	-0.025***
	(0.967)	(0.756)	(0.588)	(0.028)	(0.021)	(0.017)	(0.014)	(0.009)	(0.008)
2019 dummy	–	–	8.614***	–	–	-0.017**	–	–	0.144***
			(0.270)			(0.008)			(0.003)
Constant	99.836***	31.272***	65.767***	7.321***	8.255***	7.850***	7.864***	8.254***	7.951***
	(4.413)	(4.739)	(4.404)	(0.146)	(0.126)	(0.105)	(0.043)	(0.066)	(0.041)
Treatment effects	–	–	–	-0.052***	-0.055***	-0.051***	-0.002***	-0.003***	-0.003***
				(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Marginal effects	–	–	–	-0.214***	-0.268***	-0.233***	-0.008***	-0.014***	-0.014***
				(0.004)	(0.004)	(0.003)	(0.002)	(0.001)	(0.001)
F Value	54.44***	60.39***	88.82***	48.84***	60.27***	79.88***	70.08***	86.39***	110.90***
Adjusted R^2	0.355	0.340	0.310	0.465	0.472	0.424	0.567	0.626	0.540
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses, clustered at the village level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A5. Two-Stage Least Squares estimates using the Ogive specialization index as the endogenous variable

2*Variables	Monthly total household income			Monthly consumption expenditure		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-1.144***	-1.488***	-1.337***	-0.157***	-0.267***	-0.233***
	(0.177)	(0.243)	(0.142)	(0.055)	(0.062)	(0.043)
OSI × Climate shock (1=yes)	0.920***	1.254***	1.103***	0.146***	0.251***	0.221***
	(0.165)	(0.230)	(0.134)	(0.051)	(0.059)	(0.040)
Age of household head (years)	0.003***	0.000	0.001**	0.002***	-0.001***	0.001***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Female-headed household (1=yes)	-0.097**	-0.105***	-0.104***	-0.008	-0.078***	-0.042***
	(0.039)	(0.030)	(0.022)	(0.012)	(0.009)	(0.007)
Primary education	0.035*	0.098***	0.069***	0.044***	0.058***	0.066***
	(0.020)	(0.020)	(0.015)	(0.006)	(0.005)	(0.004)
Secondary education	0.156***	0.225***	0.198***	0.118***	0.119***	0.133***
	(0.024)	(0.029)	(0.019)	(0.008)	(0.008)	(0.006)
Higher secondary and above	0.467***	0.488***	0.467***	0.237***	0.195***	0.219***
	(0.034)	(0.032)	(0.023)	(0.011)	(0.009)	(0.007)
Household size (members)	0.040***	0.042***	0.044***	0.090***	0.118***	0.104***
	(0.007)	(0.009)	(0.005)	(0.002)	(0.003)	(0.002)
OBC (1=yes)	-0.032	-0.057**	-0.039**	-0.026***	-0.045***	-0.049***
	(0.026)	(0.027)	(0.019)	(0.009)	(0.008)	(0.006)
SC/ST (1=yes)	-0.051*	-0.029	-0.022	-0.093***	-0.092***	-0.104***
	(0.030)	(0.030)	(0.021)	(0.010)	(0.008)	(0.007)
Marginal farmer (≤2.47 acres)	-0.049	-0.301***	-0.268***	-0.077***	-0.079***	-0.084***
	(0.030)	(0.026)	(0.020)	(0.010)	(0.007)	(0.006)
Owned land size (acres)	0.062***	0.058***	0.062***	0.015***	0.012***	0.013***
	(0.004)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.006***	0.001**	0.003***	0.001***	0.000**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	-0.014	-0.346***	-0.164***	0.002	-0.053***	-0.040***
	(0.037)	(0.056)	(0.033)	(0.012)	(0.014)	(0.010)
Access to extension services	0.020	-0.008	0.000	0.052***	0.006	0.034***
	(0.024)	(0.025)	(0.018)	(0.008)	(0.007)	(0.006)
Access to credit	0.058***	-0.030	0.003	0.040***	0.031***	0.036***
	(0.019)	(0.023)	(0.015)	(0.006)	(0.006)	(0.005)
Farmer cooperative membership	0.008	0.074*	0.069**	0.001	0.025**	0.032***
	(0.044)	(0.042)	(0.030)	(0.014)	(0.012)	(0.010)
MGNREGA job card holder	-0.251***	-0.262***	-0.305***	-0.074***	-0.088***	-0.106***
	(0.032)	(0.038)	(0.027)	(0.010)	(0.010)	(0.008)
Awareness of MSP	0.144***	0.106***	0.142***	0.059***	0.044***	0.067***
	(0.024)	(0.023)	(0.017)	(0.008)	(0.006)	(0.005)
Exclusive cereals (1=yes)	-0.500***	-0.539***	-0.608***	-0.040**	-0.067***	-0.100***
	(0.060)	(0.058)	(0.043)	(0.018)	(0.015)	(0.013)
Price shock (1=yes)	0.134***	0.239***	0.189***	0.057***	0.051***	0.057***
	(0.019)	(0.024)	(0.014)	(0.006)	(0.006)	(0.004)
Yield shock (1=yes)	-0.303***	-0.124***	-0.164***	-0.014*	0.018***	0.006
	(0.025)	(0.023)	(0.014)	(0.007)	(0.006)	(0.004)
Climate shock (1=yes)	-3.280***	-3.942***	-3.690***	-0.504***	-0.768***	-0.718***
	(0.559)	(0.697)	(0.423)	(0.173)	(0.178)	(0.127)
2019 dummy	–	–	-0.299***	–	–	0.078***
			(0.047)			(0.015)
Marginal effects	-0.466***	-0.530***	-0.506***	-0.063***	-0.094***	-0.087***
	(0.072)	(0.087)	(0.054)	(0.022)	(0.022)	(0.016)
F Value	202.66***	145.29***	306.19***	440.7***	557.9***	869.6***
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Notes: Robust standard errors in parentheses, clustered at village level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A6. 2SLS estimates with squared Ogive specialization index

Variables	MPCI			MPCE		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Ogive specialisation index (OSI)	-11.211***	-8.615***	-11.023***	-1.526**	-1.632***	-2.105***
	(3.226)	(1.953)	(1.990)	(0.705)	(0.456)	(0.503)
Squared OSI (OSI^2)	1.603***	1.288***	1.617***	0.221**	0.249***	0.314***
	(0.467)	(0.297)	(0.296)	(0.102)	(0.069)	(0.075)
OSI × Climate shock (1=yes)	11.725***	9.028***	11.483***	1.497**	1.615***	2.085***
	(3.198)	(1.936)	(1.978)	(0.698)	(0.452)	(0.500)
Squared OSI × Climate shock	-1.703***	-1.379***	-1.713***	-0.216**	-0.246***	-0.310***
	(0.463)	(0.295)	(0.294)	(0.101)	(0.069)	(0.074)
Age of household head (years)	0.002**	0.002**	0.001	0.003***	0.002***	0.003***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.187***	0.036	-0.076**	0.050***	0.016**	0.032***
	(0.042)	(0.034)	(0.030)	(0.009)	(0.008)	(0.007)
Primary education	0.005	0.060***	0.047**	0.041***	0.046***	0.060***
	(0.030)	(0.022)	(0.020)	(0.007)	(0.005)	(0.005)
Secondary education	0.121***	0.149***	0.122***	0.111***	0.097***	0.114***
	(0.032)	(0.033)	(0.025)	(0.007)	(0.008)	(0.007)
Higher secondary and above	0.464***	0.451***	0.454***	0.245***	0.184***	0.219***
	(0.047)	(0.033)	(0.030)	(0.012)	(0.008)	(0.008)
Household size (members)	-0.099***	-0.103***	-0.097***	-0.074***	-0.063***	-0.068***
	(0.005)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
OBC (1=yes)	0.043	0.006	0.013	-0.018**	-0.036***	-0.041***
	(0.036)	(0.028)	(0.024)	(0.009)	(0.007)	(0.007)
SC/ST (1=yes)	0.074*	0.050	0.067**	-0.077***	-0.080***	-0.089***
	(0.043)	(0.032)	(0.028)	(0.010)	(0.008)	(0.008)
Marginal farmer (1=Yes)	0.032	-0.219***	-0.161***	-0.056***	-0.057***	-0.055***
	(0.037)	(0.024)	(0.021)	(0.009)	(0.006)	(0.006)
Owned land size (acres)	0.054***	0.055***	0.052***	0.015***	0.014***	0.013***
	(0.004)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.005***	0.000	0.002***	0.001***	0.000	0.000***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	0.061	-0.183***	-0.030	0.015	-0.016*	-0.012
	(0.042)	(0.040)	(0.031)	(0.010)	(0.009)	(0.008)
Access to extension	0.104***	0.051**	0.083***	0.056***	0.016**	0.045***
	(0.031)	(0.025)	(0.020)	(0.007)	(0.006)	(0.006)
Access to credit	0.072**	0.027	0.045**	0.026***	0.028***	0.031***
	(0.028)	(0.021)	(0.018)	(0.007)	(0.005)	(0.005)
Cooperative membership	0.139***	0.033	0.234***	0.015	0.015	0.062***
	(0.046)	(0.047)	(0.036)	(0.011)	(0.012)	(0.010)
MGNREGA job card holder	-0.101***	-0.097***	-0.118***	-0.068***	-0.062***	-0.078***
	(0.030)	(0.023)	(0.020)	(0.007)	(0.006)	(0.005)
Awareness of MSP	0.182***	0.146***	0.173***	0.068***	0.055***	0.076***
	(0.033)	(0.024)	(0.022)	(0.008)	(0.006)	(0.006)
Exclusive cereals (dummy)	-0.266***	-0.291***	-0.332***	-0.013	-0.023***	-0.053***
	(0.040)	(0.033)	(0.027)	(0.009)	(0.008)	(0.007)
Price shock (1=yes)	0.116***	0.219***	0.190***	0.052***	0.049***	0.058***
	(0.026)	(0.024)	(0.019)	(0.006)	(0.006)	(0.005)
Yield shock (1=yes)	-0.317***	-0.213***	-0.219***	-0.011	0.001	-0.005
	(0.034)	(0.021)	(0.019)	(0.008)	(0.005)	(0.005)
Climate shock (1=yes)	-17.638***	-12.639***	-16.602***	-2.262**	-2.254***	-3.016***
	(4.786)	(2.692)	(2.838)	(1.044)	(0.629)	(0.717)
2019 dummy			-0.039			0.126***
			(0.029)			(0.008)
Marginal effects	-5.616***	-3.719***	-5.086***	-0.749**	-0.693***	-0.954***
	(1.616)	(0.843)	(0.918)	(0.346)	(0.194)	(0.228)
Turning Point = $-\beta_{OSI}/2\beta_{OSI^2}$	3.497	3.344	3.409	3.454	3.278	3.351
F Value	86.54***	93.93***	150.03***	232.92***	218.28***	378.97***
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses, clustered at the village level. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

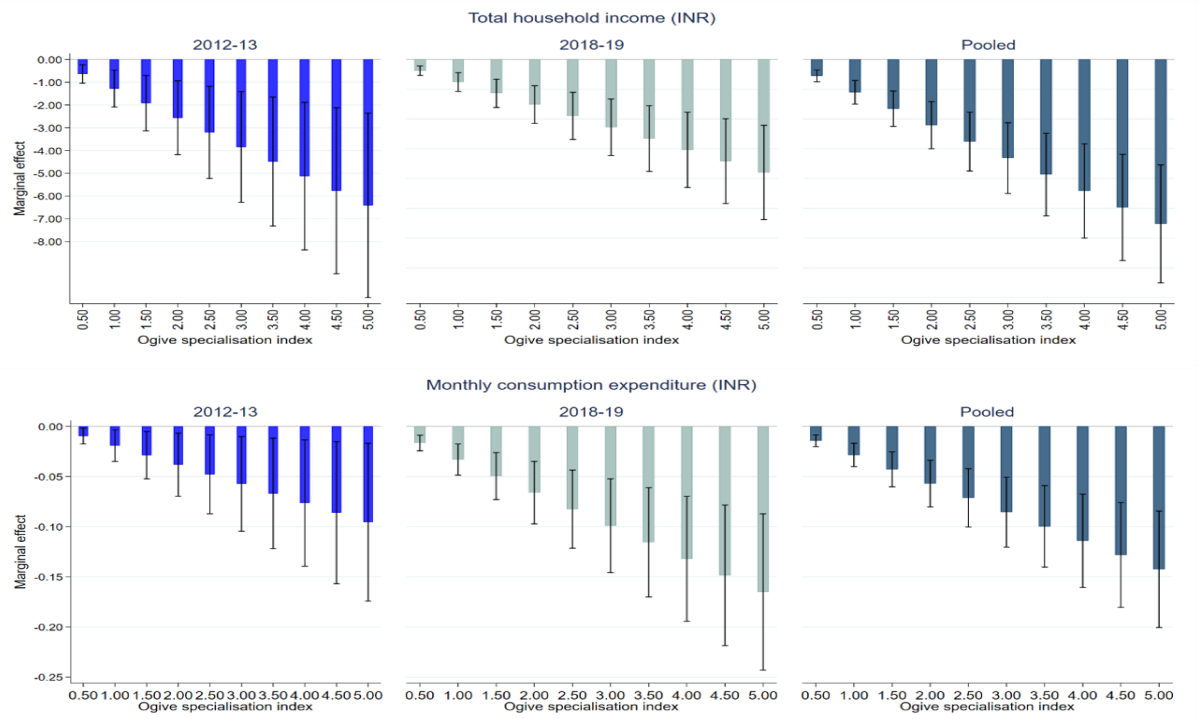

Figure A1 Marginal effects from the 2SLS model using the Ogive specialisation index

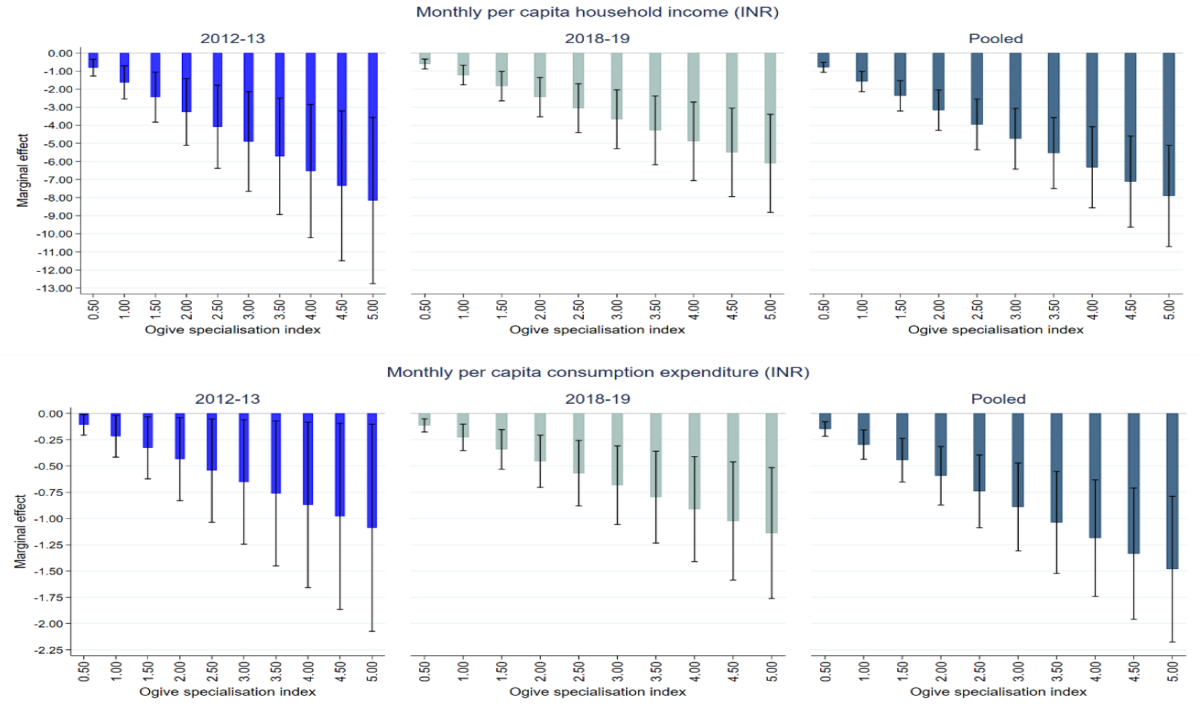

Figure A2 Marginal effects from the 2SLS model with squared Ogive specialization index

Table A7. Robustness check: 2SLS estimates with Simpson diversification index as the endogenous variable

Variables	Total household income			Monthly consumption expenditure		
	2012–13	2018–19	Pooled	2012–13	2018–19	Pooled
Simpson diversification index (SDI)	6.863***	8.930***	8.021***	0.941***	1.604***	1.396***
	(1.063)	(1.459)	(0.851)	(0.330)	(0.373)	(0.255)
SDI × Climate shock (1=yes)	-5.518***	-7.527***	-6.618***	-0.879***	-1.503***	-1.328***
	(0.993)	(1.383)	(0.802)	(0.308)	(0.354)	(0.241)
Age of household head (years)	0.003***	0.000	0.001**	0.002***	-0.001***	0.001***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Female-headed household (dummy)	-0.097**	-0.105***	-0.104***	-0.008	-0.078***	-0.042***
	(0.039)	(0.030)	(0.022)	(0.012)	(0.009)	(0.007)
Primary education	0.035*	0.098***	0.069***	0.044***	0.058***	0.066***
	(0.020)	(0.020)	(0.015)	(0.006)	(0.005)	(0.004)
Secondary education	0.156***	0.225***	0.198***	0.118***	0.119***	0.133***
	(0.024)	(0.029)	(0.019)	(0.008)	(0.008)	(0.006)
Higher secondary and above	0.467***	0.488***	0.467***	0.237***	0.195***	0.219***
	(0.034)	(0.032)	(0.023)	(0.011)	(0.009)	(0.007)
Household size (members)	0.040***	0.042***	0.044***	0.090***	0.118***	0.104***
	(0.007)	(0.009)	(0.005)	(0.002)	(0.003)	(0.002)
OBC (1=yes)	-0.032	-0.057**	-0.039**	-0.026***	-0.045***	-0.049***
	(0.026)	(0.027)	(0.019)	(0.009)	(0.008)	(0.006)
SC/ST (1=yes)	-0.051*	-0.029	-0.022	-0.093***	-0.092***	-0.104***
	(0.030)	(0.030)	(0.021)	(0.010)	(0.008)	(0.007)
Marginal farmer (1=yes)	-0.049	-0.301***	-0.268***	-0.077***	-0.079***	-0.084***
	(0.030)	(0.026)	(0.020)	(0.010)	(0.007)	(0.006)
Owned land size (acres)	0.062***	0.058***	0.062***	0.015***	0.012***	0.013***
	(0.004)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Share irrigated land (%)	0.006***	0.001**	0.003***	0.001***	0.000**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to crop markets	-0.014	-0.346***	-0.164***	0.002	-0.053***	-0.040***
	(0.037)	(0.056)	(0.033)	(0.012)	(0.014)	(0.010)
Access to extension	0.020	-0.008	0.000	0.052***	0.006	0.034***
	(0.024)	(0.025)	(0.018)	(0.008)	(0.007)	(0.006)
Access to credit	0.058***	-0.030	0.003	0.040***	0.031***	0.036***
	(0.019)	(0.023)	(0.015)	(0.006)	(0.006)	(0.005)
Cooperative membership	0.008	0.074*	0.069**	0.001	0.025**	0.032***
	(0.044)	(0.042)	(0.030)	(0.014)	(0.012)	(0.010)
MGNREGA job card holder	-0.251***	-0.262***	-0.305***	-0.074***	-0.088***	-0.106***
	(0.032)	(0.038)	(0.027)	(0.010)	(0.010)	(0.008)
Awareness of MSP	0.144***	0.106***	0.142***	0.059***	0.044***	0.067***
	(0.024)	(0.023)	(0.017)	(0.008)	(0.006)	(0.005)
Exclusive cereals (dummy)	-0.500***	-0.539***	-0.608***	-0.040**	-0.067***	-0.100***
	(0.060)	(0.058)	(0.043)	(0.018)	(0.015)	(0.013)
Price shock (1=yes)	0.134***	0.239***	0.189***	0.057***	0.051***	0.057***
	(0.019)	(0.024)	(0.014)	(0.006)	(0.006)	(0.004)
Yield shock (1=yes)	-0.303***	-0.124***	-0.164***	-0.014*	0.018***	0.006
	(0.025)	(0.023)	(0.014)	(0.007)	(0.006)	(0.004)
Climate shock (1=yes)	1.319***	2.330***	1.825***	0.229***	0.484***	0.389***
	(0.270)	(0.456)	(0.246)	(0.084)	(0.117)	(0.074)
2019 dummy			-0.299***			0.078***
			(0.047)			(0.015)
Marginal effects	0.212***	0.341***	0.281***	0.029***	0.060***	0.048***
	(0.033)	(0.056)	(0.030)	(0.010)	(0.014)	(0.009)
F Value	202.66***	145.29***	306.19***	440.70***	557.90***	869.60***
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	34350	44462	78812	34350	44462	78812

Note: Robust standard errors in parentheses, clustered at the village level. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

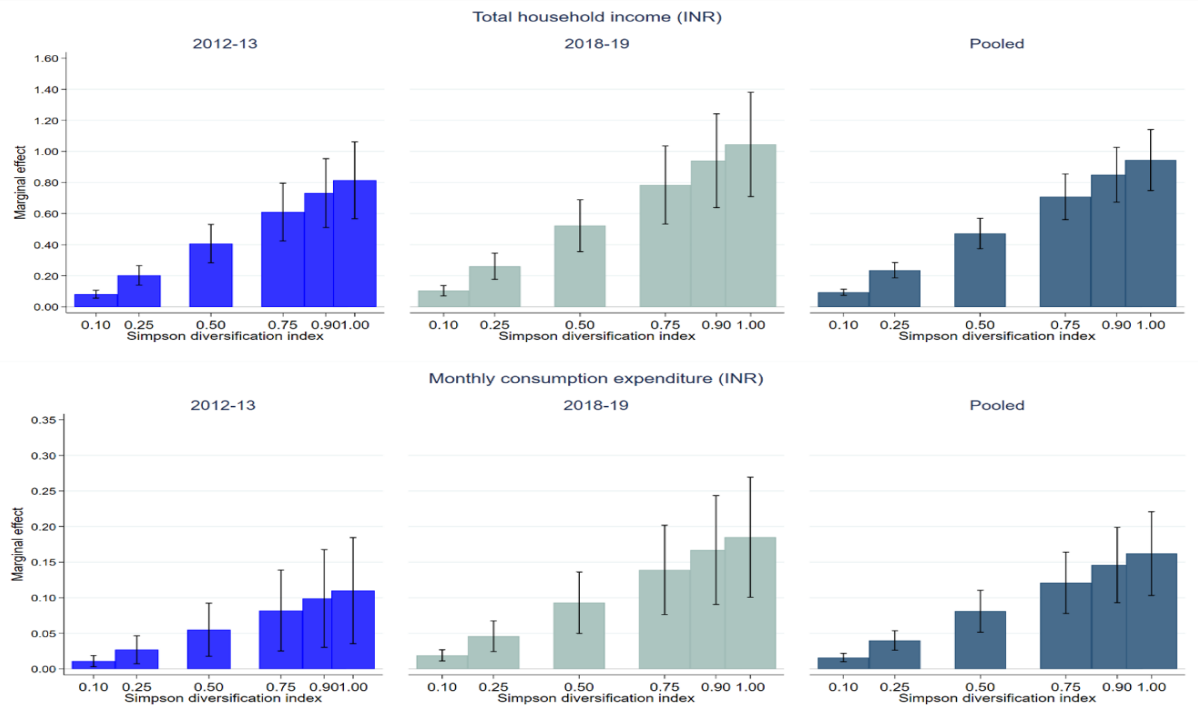

Figure A3. Marginal effects from the 2SLS model using the Simpson diversification index

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