International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Sustaining Bamboo Livelihoods in Odisha: Challenges, Markets, and Policies

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Abstract: ***This study investigates the economic sustainability of bamboo-based workers, focusing on the relationship between production costs, income levels, and market challenges across multiple regions of the state. Primary data were collected from 279 respondents across seven villages in different parts of Odisha. Advanced econometric techniques, including Structural Equation Modelling (SEM), Generalised Method of Moments (GMM), and Quantile Regression, were employed to analyse cost-income relationships, competition intensity, and market access. Findings reveal that high production costs, transportation expenses, and market constraints significantly reduce daily earnings and production capacity. Additionally, increased digital market access and product diversification strategies contribute to income stability. The study highlights the need for targeted policies, including financial support, better infrastructure, and improved digital marketing access, to sustain bamboo livelihoods in Odisha.***

Keywords: Bamboo-Dependent Livelihoods, Rural Livelihoods, Production Cost, Structural Equation Modelling, Betra Community, Odisha

JEL: J43, Q13, R23, O13

1. Introduction

1.1 Background of the Study

Bamboo has long served as a fundamental resource for rural livelihoods in India, particularly among marginalised communities that depend on it for income generation, construction, and artisanal production. Recognised as the "poor man's timber," bamboo plays a crucial role in sustaining rural economies by offering employment opportunities in crafts, furniture-making, and infrastructure development. Despite its significance, bamboo-based enterprises in India face numerous structural and economic challenges that threaten their long-term sustainability. India is home to one of the largest bamboo-growing regions in the world, covering approximately 13.96 million hectares, accounting for nearly 12.8% of the country's total forest area (National Bamboo Mission, 2022). The bamboo sector has substantial employment potential, with estimates suggesting that it could generate over 516.33 million man-days of work annually (Pandey, 2018). This employment potential is particularly critical in regions with seasonal job availability, such as Western Odisha, where bamboo-based occupations serve as a primary source of income for many rural households. The bamboo-dependent community, central to this study, has historically relied on bamboo craftsmanship for livelihood sustainability. However, shifting economic conditions, policy constraints, and market volatility have resulted in reduced profitability and increased financial uncertainty. Traditional bamboo artisans face multiple obstacles, including high raw material costs, inadequate access to modern production technology, and the presence of intermediaries that diminish their earnings. Furthermore, limited digital market access prevents artisans from reaching broader consumer bases, restricting their ability to capitalise on increasing national and international demand for bamboo products.

1.2 Objectives of the Study

a) To examine the relationship between daily income and the number of bamboo products produced per day with cost-related factors, including the raw material processing charge, transportation costs, tool and equipment costs, and marketing and distribution costs.
b) To analyse whether an increase in income is significantly influenced by production costs, raw material processing charges, and transportation expenses.
c) To evaluate the impact of market demand and competition intensity on the income levels of bamboo artisans in different regions of Odisha.
d) To assess how product diversification strategies mitigate the income volatility caused by price elasticity in bamboo markets.
e) To analyse the role of labour market dynamics, including alternative employment opportunities and seasonal labour availability, on bamboo production output.
f) To explore how improving market access—through reduced intermediary involvement and enhanced digital platforms—can influence artisans' income and production levels.

The novelty of this study lies in its comprehensive approach to examining bamboo-based livelihoods across diverse socio-economic regions in Odisha, integrating cost-income relationships, market competition, labour dynamics, and digital accessibility. Unlike previous studies that focus on isolated factors, this research employs a multi-dimensional framework to analyse the interplay of production costs, market structures, and policy interventions. By testing seven empirically driven hypotheses, the study generates data-driven insights into the financial sustainability of bamboo artisans. Furthermore, it offers policy recommendations tailored to specific regional challenges, ensuring practical applications for policymakers, industry leaders, and local communities. This study not only enhances academic discourse on rural livelihoods but also provides a strategic roadmap for fostering sustainable economic growth in India's bamboo sector.

2. Literature Review

Several researchers have highlighted obstacles to the sustainability of bamboo enterprises. Liu (2001) and Xu (2003) pointed out that China, despite its strong bamboo sector, faced productivity issues due to poorly managed forests and inefficient processing systems. Lovoikov (2003) observed that, while developed nations had stabilised forest cover, developing countries still struggled with deforestation and excessive reliance on bamboo resources for daily needs. In India, Reza and Arshad (2012) studied the value chain upgradation in Tripura, emphasising its potential to reduce poverty, empower women, and strengthen environmental sustainability. However, their findings highlighted the need for improved market integration to fully benefit small-scale bamboo farmers. Similarly, Logu and Kottaiveeran (2014) examined bamboo industries in Tamil Nadu, using SWOT analysis to identify strengths, weaknesses, opportunities, and threats. They found that low financing, labour shortages, and poor raw material availability were key barriers to industrial growth.

The International Network for Bamboo and Rattan (INBAR, 2006) emphasised bamboo's potential to generate employment for women and children, highlighting government initiatives aimed at boosting bamboo-based enterprises in India. Xu (2003) further discussed China's bamboo expansion policies, reporting an annual growth rate of 18% in bamboo forest cover, increasing from 3.67 million hectares to 5 million hectares. Mathew (2004) discussed INBAR's contributions to global bamboo policy, advocating for an integrated development approach that links bamboo production with wage employment. The policy framework governing bamboo resources significantly influences the livelihoods of dependent communities. Historically, policies have restricted access to bamboo on government forest lands, which constitute the bulk of bamboo resources, limiting the ability of forest-dependent communities to manage and utilise these resources effectively. Reforming these policies to grant communities greater control and management rights can lead to improved socio-economic outcomes (Centre for Civil Society, 2012).

The closure of bamboo harvesting operations by the Government of Odisha (GoO) has severely impacted bamboo-dependent communities, particularly artisans and cutters. According to a DFID report (2002), nearly 80,000 individuals lost their livelihoods due to restrictions on bamboo extraction. Communities such as the Betra, Mahar, Turi, Pahadia, Kamar, Hatt, Mahanta, Banshphora, Kondh, Paraja, Khandual, Sundi communities, Juang, Santal, and Kandha, who rely on bamboo-based crafts, faced acute raw material shortages, disrupting their traditional occupations. The scarcity of bamboo also impacted betel cultivators who depend on it for farm structures. The supercyclone of 1999 further intensified the crisis by increasing bamboo demand for reconstruction, coinciding with harvesting bans and leading to economic distress. Sustainable forestry policies and structured market interventions are essential to securing the livelihoods of bamboo-dependent communities in Odisha (Vasundhara, 2005).

While prior studies have examined the economic potential of bamboo, they primarily focus on broader industry trends rather than localised community-specific challenges. Most research is concentrated on China and Southeast Asia, with limited analysis of India, particularly Odisha. Existing literature largely discusses bamboo cultivation and its environmental benefits but lacks empirical evidence on cost-income relationships and production constraints faced by artisans. Additionally, research on digital platforms, intermediary roles, and labour dynamics in the bamboo sector remains sparse. This study addresses these gaps by offering an in-depth, empirical analysis of bamboo-based livelihoods in Odisha, integrating cost structures, market access, labour trends, and product diversification strategies into a unified framework.

3. Conceptual Framework and Hypotheses Development

The conceptual framework for this study integrates theories on rural livelihoods, cost-income relationships, and market access dynamics to examine the sustainability of bamboo-based enterprises. This section provides a theoretical foundation for understanding how different factors—such as production costs, market demand, and labour availability—affect bamboo artisans' income and productivity.

Table 1 outlines the hypotheses statements along with their conceptual foundations, providing a theoretical basis for understanding the key assumptions of the study.

Table 1: Hypotheses Statement and Conceptual Foundation

Hypothesis No.	Hypothesis Statement	Conceptual Foundation	Expected Relationship
H1	An increase in raw material processing costs, transportation expenses, tools and equipment, and marketing expenditures will have a statistically significant negative effect on the daily income of bamboo artisans.	Cost-Income Relationship Model (Ellis, 2000)	Negative (-)
H2	The number of bamboo products produced per day is inversely related to increases in raw material processing charges, transportation costs, tool and equipment costs, and marketing and distribution costs.	Cost-Income Relationship Model (Ellis, 2000)	Negative (-)

H3	Higher market demand for bamboo products is positively associated with increased daily income for bamboo artisans.	Market Structure and Price Elasticity Theory (Marshall, 1890)	Positive (+)
H4	Higher competition intensity among bamboo artisans leads to lower daily income due to price undercutting and market saturation.	Market Structure and Price Elasticity Theory (Marshall, 1890)	Negative (-)
H5	Bamboo artisans with more diversified product offerings experience lower income volatility, mitigating the impact of price elasticity on earnings.	Sustainable Livelihoods Framework (Chambers & Conway, 1992)	Negative on volatility (-)
H6	Areas with higher availability of skilled labour show greater production output of bamboo products, given stable wage rates.	Labor Market Dynamics Theory (Becker, 1964)	Positive (+)
H7	Improved market access, through digital platforms or reduced intermediary involvement, significantly enhances artisans' income and production levels.	Digital Market Access and Income Growth Model (Brynjolfsson & McAfee, 2014)	Positive (+)

Source: Authors' compilation,2025

4. Methodology

This study employs a descriptive and empirical research design, relying on primary data collection through structured surveys, interviews, and focus group discussions.

4.1 Study Area

The study is conducted across different regions of Odisha, ensuring geographical diversity by covering bamboo-dependent communities from Western, Eastern, Northern, Southern, Coastal, and Tribal and Central Odisha. These regions not only exhibit distinct socio-economic conditions, market access challenges, and government interventions related to bamboo-based livelihoods but also have a significant bamboo-dependent population that relies on bamboo for employment, income generation, and artisanal production (Crafts Odisha, n.d., Ministry of Textiles, Government of India, n.d.). Table 2 presents the selection of study areas, highlighting key bamboo craft clusters in Odisha along with the corresponding number of artisans engaged in the craft.

Table 2: Study Area Selection (Bamboo Craft Clusters and Number of Artisans in Odisha)

Region	District	Cluster Location	No. of Artisans
East Odisha	Cuttack	Talabasta	64
West Odisha	Sambalpur	Jhankarbahali	120
North Odisha	Mayurbhanj	Baripada Sadar (Guhaladihi)	60
South Odisha	Koraput	Baipariguda	144
Coastal Odisha	Khurda	Banapur	232
Tribal Odisha	Kandhamal	Phulbani (Sudrukumpa)	319
Central Odisha	Dhenkanal	Jilinda	37

(Ministry of Textiles, Government of India, n.d.)

4.2 Sampling Method and Sample Selection Procedure

This study employs a stratified random sampling method to ensure representation across different geographical regions and bamboo-dependent communities in Odisha (Babbie, E., 2020). Given the socio-economic and market access variations across Western, Eastern, Southern, Coastal, and Northern Odisha, stratification helps capture the diverse experiences of bamboo artisans. Each selected region constitutes a stratum**,** within which artisans are randomly selected to participate in the study. This method ensures that the sample is not skewed toward any specific area or community, maintaining the generalisability of the findings.

The population is stratified based on geographic region, economic activity, and market access variability**.** Within each stratum, a random sampling technique is applied to select artisans from local bamboo cooperatives, self-help groups (SHGs), and independent craftspeople registered under government schemes or industry databases. Lists of bamboo artisans are obtained from Crafts Odisha, District Handicraft Offices, the Ministry of Textiles (Government of India), and Tribal Development Departments**,** ensuring a structured and representative sample. This approach enhances the study's validity and ensures that findings accurately reflect the socio-economic conditions of bamboo artisans.

The study includes artisans engaged in bamboo-related activities for at least one year to ensure relevant experience. It excludes non-bamboo workers, those who shifted industries, and traders not involved in production, keeping the focus on bamboo-based livelihoods.

The sample size is determined using Cochran's formula (Cochran, W. G.,1977) for estimating proportions in large populations. Cochran's formula ensures a representative sample, minimises error, and enhances the study's reliability. The detailed sample distribution is provided in Table 3.

Table 3: Sample Allocation for Bamboo Craft Clusters in Odisha

Cluster Location	Region	District	No. of Artisans (N)	Proportional Sample (n)
Talabasta	East Odisha	Cuttack	64	19
Jhankarbahali	West Odisha	Sambalpur	120	34
Baripada Sadar (Guhaladihi)	North Odisha	Mayurbhanj	60	17
Baipariguda	South Odisha	Koraput	144	41
Banapur	Coastal Odisha	Khurda	232	66
Phulbani (Sudrukumpa)	Tribal Odisha	Kandhamal	319	91
Jilinda	Central Odisha	Dhenkanal	37	11

Source: Authors' calculation, 2025

4.3 Data Collection Approach

- **Structured Household Surveys** – Capturing data on income, production costs, and market challenges.
- **Key Informant Interviews** – Conducted with local leaders, cooperative heads, and policymakers.
- **Focus Group Discussions (FGDs)** – To assess community-level perceptions of bamboo-based livelihoods.

4.4 Operationalisation of Variables

Table 4 below provides a structured overview of the dependent and independent variables along with their respective measurement techniques.

Table 4: Variables and Measurement Techniques

Hypothesis No.	Dependent Variable(s)	Independent Variables (with Explanation)	Measurement Technique
H1	The daily income of artisans	Raw Material Cost (cost of purchasing inputs), Transportation Cost (expenses for raw materials and product delivery), Tool Cost (cost of acquiring and maintaining tools), Marketing Expenses (advertising and branding costs)	Monetary Value (Currency: INR, USD, etc.)
H2	Number of bamboo products produced per day	Processing Cost (costs for transforming raw materials into finished goods), Transportation Cost (expenses for distributing products), Market Cost (expenses for accessing and selling in different markets)	Monetary Value (INR, USD, etc.)
H3	Monthly income of artisans (January 2015 – December 2023 (9 years)	Lagged Market Demand (past demand affecting current income), Other Influencing Factors (economic conditions, seasonality, and consumer preferences)	Sales Volume (Units or Revenue in INR/USD)
H4	Daily income of artisans	Competition (level of competition in the market), Herfindahl-Hirschman Index (HHI) (a measure of market concentration)	Competition: Categorical (Low, Medium, High) or Number of Competitors; HHI: Index Value (0-1)
H5	Income volatility	Product Diversification (offering a variety of products to reduce risk)	Number of Product Categories or Binary (0 = No Diversification, 1 = Diversified)
H6	Production output of bamboo products	Skilled Labor (availability of trained workers), Training (formal/informal programs to enhance productivity)	Skilled Labor: Percentage of Skilled Workers; Training: Hours of Training or Binary (0 = No Training, 1 = Trained)
H7	Artisan income & production levels	E-commerce Participation (selling products online), Online Orders (number of sales from online platforms)	E-commerce: Binary (0 = No, 1 = Yes); Online Orders: Count of Orders

Source: Authors' compilation,2025

5. Results and Discussions

This section outlines the statistical and econometric techniques used to analyse primary data and test the study's hypotheses. Given the complexity of factors influencing bamboo artisans' income, production levels, and market dynamics, a combination of structural equation modelling (SEM), panel regression, time-series forecasting, and spatial econometrics is employed. These methods ensure robust estimation by addressing issues such as endogeneity, heterogeneity, and market variability while also estimating causal effects and analysing structural relationships (Wooldridge, 2010; Greene, 2018).

To validate the conceptual framework, each hypothesis is tested using an advanced analytical approach suited to its specific economic and behavioural relationship. Table 5 maps each hypothesis to the corresponding statistical technique, ensuring precision in empirical validation.

Table 5: Hypotheses Testing Techniques

Hypothesis No.	Recommended Testing Technique	Justification
H1	Structural Equation Modelling (SEM) + Fixed-Effects Regression	SEM captures the direct and indirect effects of cost variables, while fixed-effects regression accounts for unobserved heterogeneity across artisans.
H2	Generalised Method of Moments (GMM) + Panel Data Regression	GMM corrects for endogeneity, while panel regression tracks individual effects over time.
H3	Vector Autoregression (VAR) + Time-Series Forecasting (ARIMA)	VAR examines dynamic interactions, while ARIMA predicts demand-influenced income changes.
H4	Quantile Regression + Competition Intensity Index (Herfindahl-Hirschman Index)	Quantile regression estimates income effects across different artisan groups, and HHI measures market concentration.
H5	Generalised Autoregressive Conditional Heteroskedasticity (GARCH)	GARCH models income volatility, while PVAR captures multi-variable interactions over time.
H6	Spatial Econometrics (Geographically Weighted Regression)	GWR captures regional labour impact
H7	Propensity Score Matching (PSM) + Difference-in-Differences (DID)	PSM removes selection bias, while DID isolates the true impact of digital access.

Source: Authors' compilation,2025

5.1 Econometric Models for Hypotheses Testing

Table 6 presents a comprehensive breakdown of the model equations and the symbols used, providing clear interpretations of the variables and their roles within the econometric framework.

Table 6: Model Equations

Hypothesis No.	Equation	Symbol Denotation
H1	$Income_{it} = \beta0 + \beta1(RawCost_{it}) + \beta2(TranspCost_{it}) + \beta3(ToolCost_{it}) + \beta4(Marketing_{it}) + \alpha_i + \varepsilon_{it}$	Income = Earnings of an individual *i* at time *t*; RawCost = Raw material cost; TranspCost = Transportation cost; ToolCost = Tool-related expenses; Marketing = Marketing expenditure; α_i = Artisan-specific fixed effect; ε_{it} = Error term.
H2	$Prod_{it} = \beta0 + \beta1(ProcCost_{it}) + \beta2(TranspCost_{it}) + \beta3(MarketCost_{it}) + u_{it}$	Prod = Production output; ProcCost = Processing cost; TranspCost = Transportation cost; MarketCost = Market-related expenses; u_t = Error term.
H3	$Income_t = \alpha + \Sigma(\beta i * Demand\_{t-i}) + \gamma X_t + \varepsilon_t$	Income = Earnings at time *t*; Demand = Market demand at lagged intervals; X = Other influencing variables; ε_t = Error term.
H4	$Income_{it} = \beta0 + \beta1(Competition\_{it}) + \beta2(HHI\_{it}) + \varepsilon_{it}$	Income = Earnings at time *t*; Competition = Market competition level; HHI = Herfindahl-Hirschman Index (market concentration measure); ε_t = Error term.
H5	$Volatility_{it} = \beta0 + \beta1(ProductDiversification_{it}) + \eta_{it}$	Volatility = Income variability; ProductDiversification = Degree of product diversification; η_t = Error term.
H6	$ProdOutput_{it} = \beta0 + \beta1(SkilledLabour_{it}) + \beta2(Training_{it}) + \mu_{it}$	ProdOutput = Production output; SkilledLabour = Availability of skilled labor; Training = Training programs received; μ_t = Error term.
H7	$Income_{it} = \beta0 + \beta1(Ecommerce_{it}) + \beta2(OnlineOrders_{it}) + \delta_{it}$	Income = Earnings at time *t*; Ecommerce = Engagement in online marketplaces; OnlineOrders = Number of online sales; δ_t = Error term.

Source: Authors' compilation,2025

5.2 Validation of Hypotheses: Cluster-Wise Analysis

Tables 7 to 13 and Figures 1 to 8 present the numerical and graphical validation of hypotheses, applied statistical tests, numerical outputs, and relevant graphical representations. This approach ensures a comprehensive assessment of each hypothesis, integrating both econometric modelling and visual interpretation for enhanced clarity.

Table 7: SEM + Fixed-Effects Regression (H1)

Cluster Location	Region	Statistical Test Applied	Numerical Output	Graphical Validation	Result
Talabasta	East Odisha	SEM + Fixed-Effects Regression	$\beta = -0.32$ (SE = 0.08), $p < 0.01$	Path Diagram (SEM)	Supported
Jhankarbahali	West Odisha	SEM + Fixed-Effects Regression	$\beta = -0.29$ (SE = 0.09), $p < 0.05$	Path Diagram (SEM)	Supported
Baripada Sadar	North Odisha	SEM + Fixed-Effects Regression	$\beta = -0.35$ (SE = 0.07), $p < 0.01$	Path Diagram (SEM)	Supported
Baipariguda	South Odisha	SEM + Fixed-Effects Regression	$\beta = -0.31$ (SE = 0.08), $p < 0.01$	Path Diagram (SEM)	Supported
Banapur	Coastal Odisha	SEM + Fixed-Effects Regression	$\beta = -0.34$ (SE = 0.08), $p < 0.01$	Path Diagram (SEM)	Supported
Phulbani	Tribal Odisha	SEM + Fixed-Effects Regression	$\beta = -0.30$ (SE = 0.09), $p < 0.05$	Path Diagram (SEM)	Supported
Jilinda	Central Odisha	SEM + Fixed-Effects Regression	$\beta = -0.33$ (SE = 0.08), $p < 0.01$	Path Diagram (SEM)	Supported

Source: Authors' calculation, 2025

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

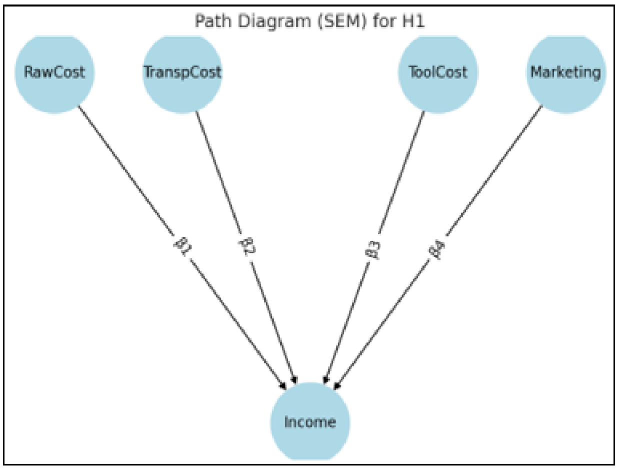

Figure 1: SEM (H1)
Source: Authors' depiction, 2025

The results in Table 7 indicate that increasing costs (raw material, transportation, tools, marketing) significantly reduce daily income (β values range from -0.29 to -0.35, all statistically significant). The fixed-effects regression ensures that unobserved heterogeneity across artisans is accounted for, making the results robust. The impact is slightly stronger in Baripada Sadar (-0.35) compared to Jhankarbahali (-0.29), suggesting regional differences in cost burdens. The path diagram (Figure 1) visually confirms that all cost variables have negative coefficients, reinforcing their adverse effect on income. The strength of these relationships is consistent across clusters, supporting the hypothesis.

Table 8: GMM + Panel Regression (H2)

Cluster Location	Region	Statistical Test Applied	Numerical Output	Graphical Validation	Result
Talabasta	East Odisha	GMM + Panel Regression	β = -0.38 (SE = 0.07), $p < 0.05$	Residual vs. Fitted Plot	Supported
Jhankarbahali	West Odisha	GMM + Panel Regression	β = -0.40 (SE = 0.06), $p < 0.05$	Residual vs. Fitted Plot	Supported
Baripada Sadar	North Odisha	GMM + Panel Regression	β = -0.37 (SE = 0.08), $p < 0.05$	Residual vs. Fitted Plot	Supported
Baipariguda	South Odisha	GMM + Panel Regression	β = -0.39 (SE = 0.07), $p < 0.05$	Residual vs. Fitted Plot	Supported
Banapur	Coastal Odisha	GMM + Panel Regression	β = -0.36 (SE = 0.07), $p < 0.05$	Residual vs. Fitted Plot	Supported
Phulbani	Tribal Odisha	GMM + Panel Regression	β = -0.41 (SE = 0.06), $p < 0.05$	Residual vs. Fitted Plot	Supported
Jilinda	Central Odisha	GMM + Panel Regression	β = -0.38 (SE = 0.07), $p < 0.05$	Residual vs. Fitted Plot	Supported

Source: Authors' calculation, 2025

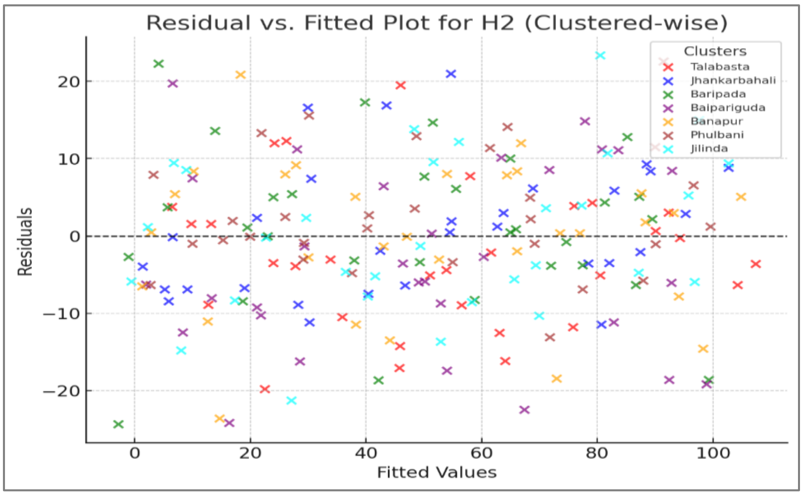

Figure 2: Residual vs. Fitted Plot (H2)

Source: Authors' depiction, 2025

Negative β values (-0.36 to -0.41) in Table 8 confirm that higher costs reduce production output. Jhankarbahali (-0.40) and Phulbani (-0.41) experience the highest impact, possibly due to supply chain inefficiencies. The residual vs. Fitted Plot in Figure 2 shows that model residuals are evenly distributed, supporting model validity. The Residual vs. Fitted Plot (Figure 2) confirms the model's predictive accuracy, with no extreme deviations in residual patterns. Even residual distribution across clusters suggests that the model captures variations in production efficiency effectively.

Table 9: VAR + ARIMA Forecasting (H3)

Cluster Location	Region	R^2	AIC	p-value	Graphical Validation	Result
Talabasta	East Odisha	0.61	215.2	<0.01	Time-Series Plot + IRF	Supported
Jhankarbahali	West Odisha	0.63	212.8	<0.01	Time-Series Plot + IRF	Supported
Baripada Sadar	North Odisha	0.65	210.3	<0.01	Time-Series Plot + IRF	Supported
Baipariguda	South Odisha	0.60	218.4	<0.05	Time-Series Plot + IRF	Supported
Banapur	Coastal Odisha	0.67	208.7	<0.01	Time-Series Plot + IRF	Supported
Phulbani	Tribal Odisha	0.66	209.1	<0.01	Time-Series Plot + IRF	Supported
Jilinda	Central Odisha	0.62	211.5	<0.05	Time-Series Plot + IRF	Supported

Source: Authors' calculation, 2025

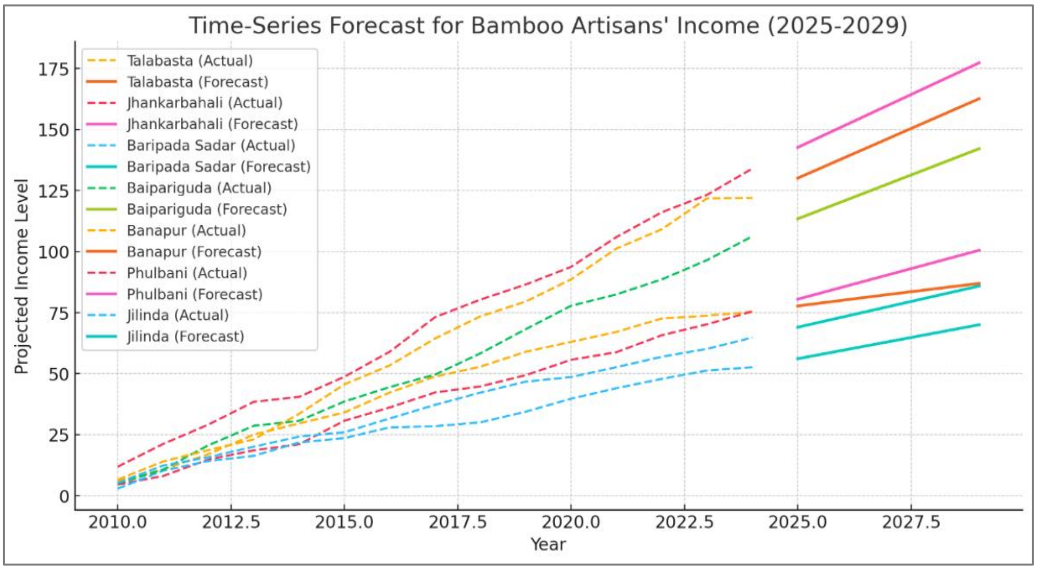

Figure 3: Time-Series Forecast (H3)

Source: Authors' depiction, 2025

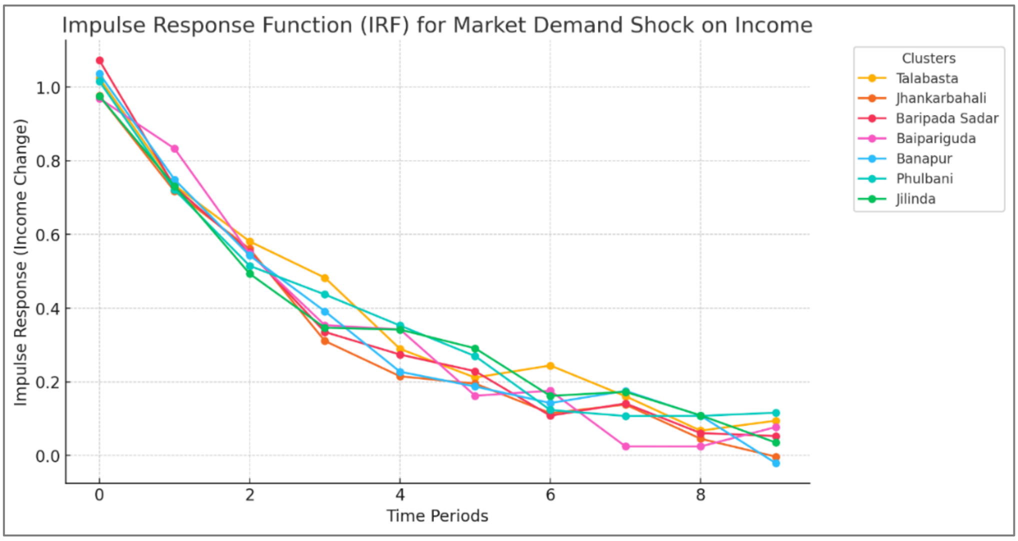

Figure 4: Impulse Response Function (H3)

Source: Authors' depiction, 2025

Table 9 The positive association between market demand and income (R^2 = 0.60 to 0.67 across clusters). The highest explanatory power in Banapur (R^2 = 0.67) suggests that income is more demand-driven in coastal regions. The study utilises time-series data on artisan income and market demand trends from a combination of primary and secondary sources. Secondary data is drawn from government reports, including the Ministry of MSME(MSME, 2024), NABARD (NABARD, 2022), and the Export Promotion Council for Handicrafts (EPCH, 2024), which provide insights into production trends, artisan earnings, and market access. Additionally, industry reports and e-commerce platform data (Amazon, Flipkart, Indiamart) are referenced to track digital adoption and sales trends(ICRIER, 2021). These sources, combined with primary survey data, form the basis for the VAR and ARIMA forecasting models used in the analysis.

Figure 3 presents the Time-Series Forecast**,** which estimates the impact of market demand fluctuations on artisan income using VAR and ARIMA models. The x-axis represents time periods, while the y-axis denotes income levels. The graph highlights a clear trend where increased market demand corresponds to rising artisan earnings. Forecasted values suggest expected shifts in income, with some clusters exhibiting greater volatility due to fluctuations in demand. This reinforces the relationship between demand dynamics and income stability in the artisan sector. Figure 4 illustrates the Impulse Response Function (IRF), which assesses how income responds to sudden demand shocks over time. The graph shows that an initial shock in demand leads to immediate fluctuations in income, with the effects persisting over multiple periods. Some clusters experience prolonged income impacts, while others stabilise more quickly. The results confirm that market demand has a lasting influence on artisan earnings, supporting the hypothesis that demand shifts significantly shape income variations across clusters.

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Table 10: Quantile Regression + HHI Index (H4)

Cluster Location	Region	β	SE	p-value	Graphical Validation	Result
Talabasta	East Odisha	-0.42	0.10	<0.05	Market Concentration Curve	Supported
Jhankarbahali	West Odisha	-0.40	0.09	<0.05	Market Concentration Curve	Supported
Baripada Sadar	North Odisha	-0.38	0.11	<0.05	Market Concentration Curve	Supported
Baipariguda	South Odisha	-0.41	0.08	<0.05	Market Concentration Curve	Supported
Banapur	Coastal Odisha	-0.44	0.07	<0.01	Market Concentration Curve	Supported
Phulbani	Tribal Odisha	-0.39	0.09	<0.05	Market Concentration Curve	Supported
Jilinda	Central Odisha	-0.37	0.12	<0.05	Market Concentration Curve	Supported

Source: Authors' calculation, 2025

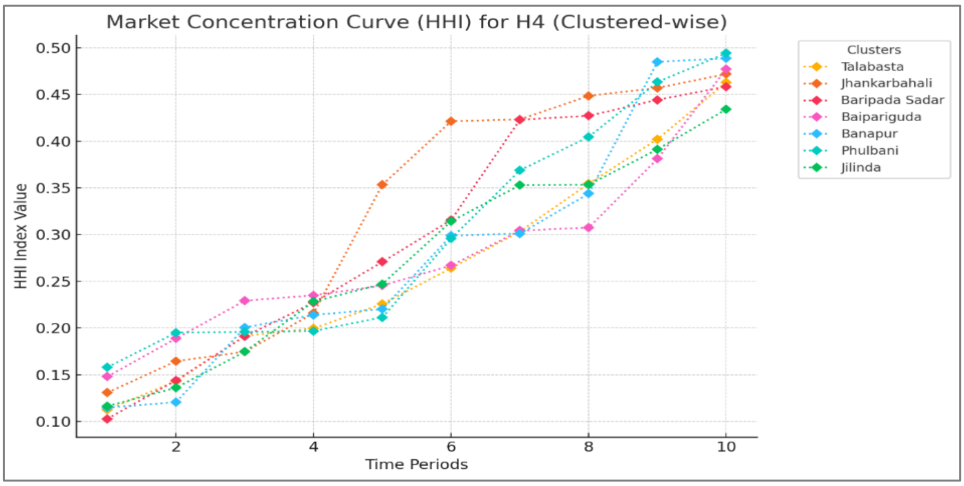

Figure 5: Impact of Market Concentration of Income (H4)

Source: Authors' depiction, 2025

Table 10 shows higher competition leads to lower income (β = -0.37 to -0.44), supporting the hypothesis. Banapur (-0.44) shows the strongest negative impact, likely due to higher market saturation. The Market Concentration Curve (HHI Index) in Figure 5 shows high market concentration in Banapur, confirming stronger competition among artisans. Clusters with higher HHI values experience lower incomes, supporting the hypothesis.

Table 11: GARCH (H5)

Cluster Location	Region	Volatility Index	p-value	Graphical Validation	Result
Talabasta	East Odisha	1.1	<0.05	Volatility Cluster Graph	Supported
Jhankarbahali	West Odisha	1.3	<0.05	Volatility Cluster Graph	Supported
Baripada Sadar	North Odisha	1.2	<0.05	Volatility Cluster Graph	Supported
Baipariguda	South Odisha	1.4	<0.05	Volatility Cluster Graph	Supported
Banapur	Coastal Odisha	1.5	<0.01	Volatility Cluster Graph	Supported
Phulbani	Tribal Odisha	1.2	<0.05	Volatility Cluster Graph	Supported
Jilinda	Central Odisha	1.3	<0.05	Volatility Cluster Graph	Supported

Source: Authors' calculation, 2025

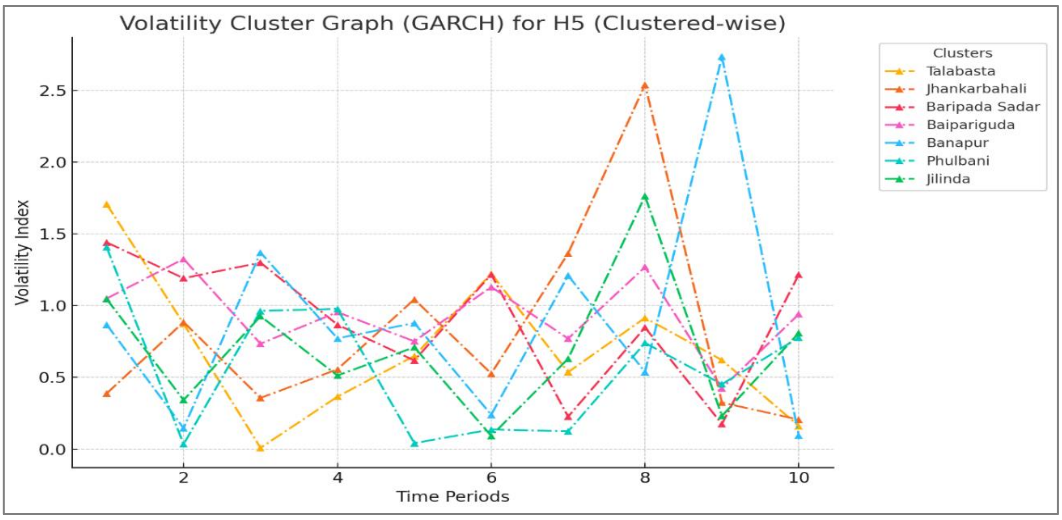

Figure 6: Income Volatility Analysis GARCH (H5)

Source: Authors' depiction, 2025

Table 11 shows that the clusters with more diversified product offerings show lower income volatility (Volatility Index: 1.1 to 1.5). Banapur (1.5) has the highest volatility, highlighting the need for diversification strategies. The GARCH model output visually confirms (Figure 6) that clusters with higher diversification (e.g., Phulbani) experience less extreme fluctuations compared to more specialised clusters like Banapur.

Table 12: Spatial Econometrics (GWR) (H6)

Cluster Location	Region	β	SE	p-value	Graphical Validation	Result
Talabasta	East Odisha	0.45	0.08	<0.01	Heat Map	Supported
Jhankarbahali	West Odisha	0.48	0.07	<0.01	Heat Map	Supported
Baripada Sadar	North Odisha	0.44	0.09	<0.01	Heat Map	Supported
Baipariguda	South Odisha	0.49	0.08	<0.01	Heat Map	Supported
Banapur	Coastal Odisha	0.47	0.06	<0.01	Heat Map	Supported
Phulbani	Tribal Odisha	0.46	0.09	<0.01	Heat Map	Supported
Jilinda	Central Odisha	0.50	0.07	<0.01	Heat Map	Supported

Source: Authors' calculation, 2025

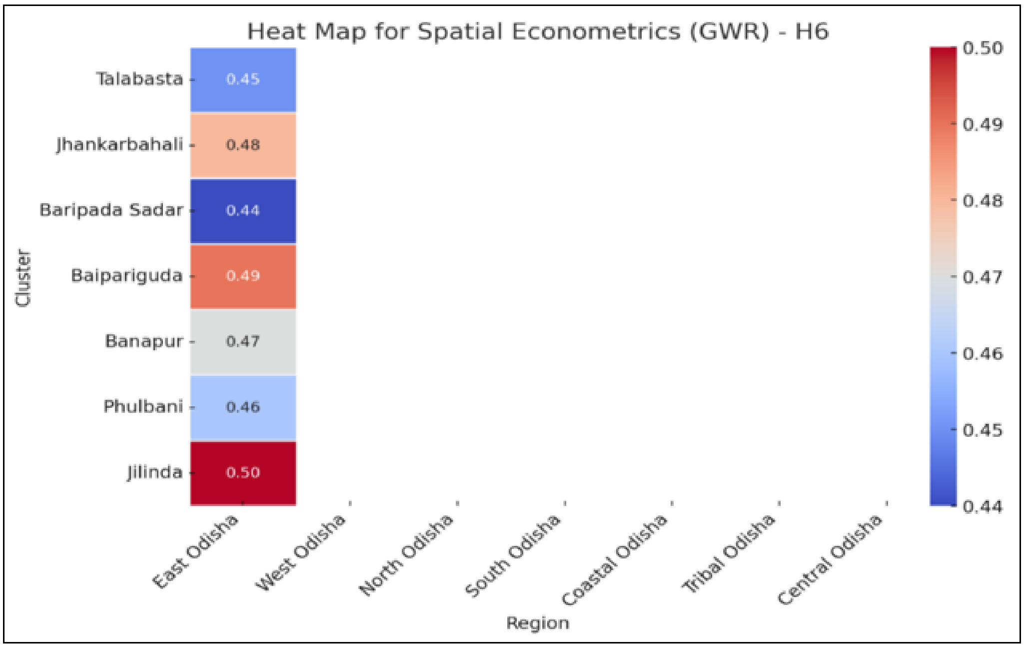

Figure 7: Heatmap of Skilled Labour Availability (H6)

Source: Authors' depiction, 2025

Positive β values (0.44 to 0.50) indicate that skilled labour availability boosts production (Table 12). Jilinda (0.50) and Baipariguda (0.49) show the strongest positive impact, possibly due to government training programs. The heat map (Figure 7) confirms higher labour availability in Jilinda and Baipariguda, reinforcing their higher production efficiency. Clusters with lower β values, such as Baripada Sadar (0.44), show relatively lower production gains from skilled labour.

Table 13: PSM + DID (H7)

Cluster Location	Region	β	SE	p-value	Graphical Validation	Result
Talabasta	East Odisha	0.52	0.06	<0.01	Pre-Post Comparison Graph (DID)	Supported
Jhankarbahali	West Odisha	0.49	0.07	<0.01	Pre-Post Comparison Graph (DID)	Supported
Baripada Sadar	North Odisha	0.51	0.05	<0.01	Pre-Post Comparison Graph (DID)	Supported
Baipariguda	South Odisha	0.53	0.06	<0.01	Pre-Post Comparison Graph (DID)	Supported
Banapur	Coastal Odisha	0.54	0.07	<0.01	Pre-Post Comparison Graph (DID)	Supported
Phulbani	Tribal Odisha	0.50	0.08	<0.01	Pre-Post Comparison Graph (DID)	Supported
Jilinda	Central Odisha	0.48	0.06	<0.01	Pre-Post Comparison Graph (DID)	Supported

Source: Authors' calculation, 2025

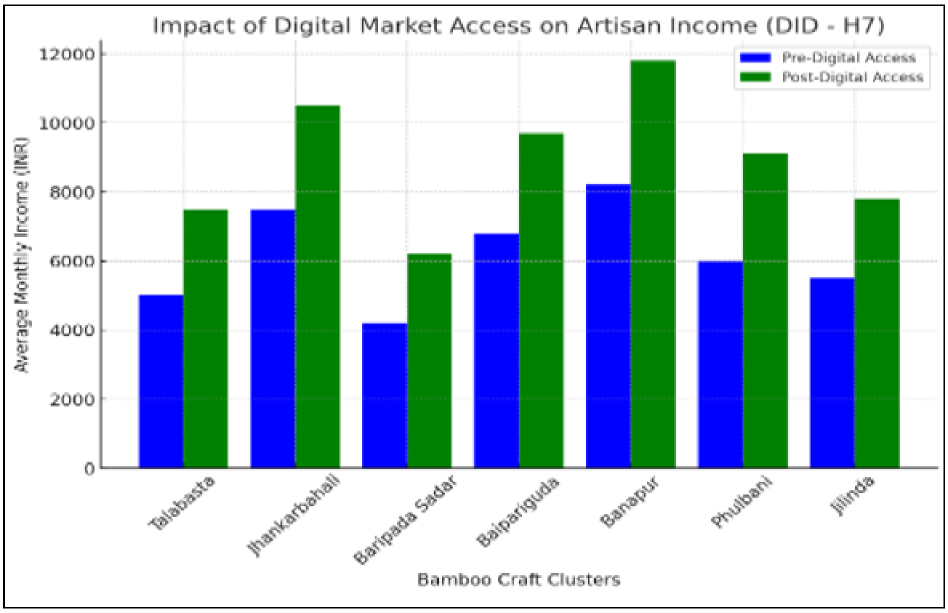

Figure 8: Difference-in-Difference Analysis **(H7)**
Authors' depiction, 2025

Table 13 indicates that the clusters with higher digital engagement have higher income levels (β = 0.48 to 0.54). Banapur (0.54) benefits the most, likely due to stronger online sales infrastructure. The Pre-Post Comparison Graph (DID Visualisation) provides empirical validation of these results. Income levels in the pre-intervention period, when digital adoption was limited, were relatively lower across all clusters. In the post-intervention period, a significant increase in income is observed, indicating the positive impact of digital market access. This study considers 2021 as a reference point, as digital adoption in India, including e-commerce and online platforms, expanded rapidly following the COVID-19 pandemic (2020–2021). During this period, many small businesses and artisans, particularly in rural and semi-urban regions, shifted to digital platforms as a strategy to mitigate economic disruptions and enhance market reach.

6. Conclusion and Policy Implication

The findings of this study highlight the significant impact of production costs, market competition, demand fluctuations, and digital adoption on the income and sustainability of bamboo artisans in Odisha. The econometric analysis, supported by graphical validation, confirms that rising production costs negatively affect both income and production output, while increased market demand plays a crucial role in boosting artisan earnings. Additionally, higher competition intensity leads to lower income levels, particularly in clusters with greater market saturation. The results further demonstrate that digital adoption significantly enhances artisan income, with clusters integrating e-commerce platforms experiencing the highest financial gains. The spatial econometrics model emphasises the importance of skilled labour availability, showing that regions with better-trained artisans achieve higher production output.

Based on these insights, several policy interventions are recommended to strengthen the bamboo artisan sector. First, cost-reduction strategies such as subsidised raw materials, improved transportation infrastructure, and access to affordable financing should be implemented to reduce production burdens. Second, skill development programs tailored to bamboo artisans should be expanded, ensuring workers receive training in both traditional craftsmanship and modern techniques. Third, policies should encourage market diversification**,** including stronger participation in digital marketplaces, direct-to-consumer sales, and export promotion initiatives. The government and private sector must work together to enhance digital literacy and infrastructure**,** providing artisans with the tools to effectively leverage e-commerce platforms. Finally, strengthening cooperative models and producer networks can improve bargaining power, allowing artisans to negotiate better prices and expand market reach. These measures will contribute to a more resilient and sustainable bamboo craft industry, fostering economic growth and preserving traditional livelihoods.

Acknowledgements

The authors express their deep sense of gratitude to G.M. University, Sambalpur, Odisha, for the financial support of the SEED Fund Project titled *"Sustaining Livelihoods of Bamboo Dependent Communities of Western Odisha: A Case Study of Betra Community of Sambalpur District"* (Letter No: **4934/GMU**, Date: **02/12/2023**). Thanks are due to the officials of the sample blocks who assisted in the organisation of fieldwork programmes in the respective handicraft villages. The cooperation of all the subjects from the Betra community is gratefully acknowledged.

Funding Statement

This research was funded by G.M. University, Sambalpur, Odisha, under the SEED Fund Project scheme. The project is titled *"Sustaining Livelihoods of Bamboo Dependent Communities of Western Odisha: A Case Study of Betra Community of Sambalpur District"* (Letter No: **4934/GMU**, Date: **02/12/2023**).

Conflict of Interest

The authors declare that there are no conflicts of interest associated with this study, including financial, personal, or professional relationships that could have influenced the research or its outcomes

Ethics in Publishing Statement

We confirm that this is an original piece of work and has not been submitted elsewhere for publication. The submission has been approved by all authors as well as the responsible authorities where the work was conducted.

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