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Impact of Technological Interventions on Efficiency, Transparency, and Sustainability of Minor Forest Produce Supply Chain Networks in Chhattisgarh

Rishi Kumar Rai[1]*, Dr. Sumita Dave[2]
[1] Research Scholar, Amity Business School, Amity University Chhattisgarh, India. Email: rishi.rai@s.amity.edu
[2] Professor, Amity Business School, Amity University Chhattisgarh, India. Email: sdave@rpr.amity.edu
Corresponding Author:
Rishi Kumar Rai[1]*
Email: rishi.rai@s.amity.edu

ABSTRACT
In Chhattisgarh, Minor Forest Produce (MFP) is a key source of livelihood for ~75 lakh tribal collectors dependent on forest and the state government in association with Chhattisgarh State Minor Forest Produce (Trading & Development) Co-operative Federation (CGMFPFED) and Tribal Cooperative Marketing Development Federation of India (TRIFED), subsidiary of the Ministry as well has gradually rolled out seven categories digital interventions to upgrade its supply chain network. In this context, the present study hypothesizes and tests empirically that these technological interventions does not improve efficiency, transparency and sustainability of minimum farm price (MFP) supply chain networks in Chhattisgarh. We used a mixed methods cross-sectional study design in which 412 respondents, consisting of primary collectors, Van Dhan SHG members, CGMFPFED procurement staff and federation logistics personnel were surveyed during the period October–November 2021 from fifteen districts of Bastar division/northern Chhattisgarh. There were seven independent technology constructs (mobile e-procurement, GIS/GPS mapping, blockchain traceability, direct benefit transfer for Minimum Support Price payments, IoT-based storage monitoring, Van Dhan e-commerce platforms and quality-grading mobile applications) operationalised through validated multi-item scales and three dependent supply-chain constructs (efficiency, transparency, sustainability), which were triangulated with secondary data on procurement from the CGMFPFED for five flagship MFPs: tendu leaves; mahua flower; sal seed; tamarind; and harra/baheda during 2020–2025. The results of multiple regression analysis showed standardized coefficients with ranges of $\beta = 0.16$ to $\beta = 0.42$, $p < 0.05$; the adjusted R^2 were: 0.61 (efficiency), 0.68 (transparency) and 0.54 (sustainability). Across the fifteen districts surveyed, the composite supply chain performance index increased from a mean of 0.33 in low-adoption clusters to 0.73 in high-adoption clusters. The null hypothesis is thus rejected at the 99 % confidence level, and we conclude that technological interventions had a large, statistically significant and practically relevant effect on all three supply-chain outcomes, with blockchain traceability dominating transparence dimension over digital benefit transfer dominating efficiency dimension and GIS-based harvest mapping dominating sustainability dimension.

Keywords *Minor Forest Produce, Chhattisgarh, Supply Chain, Blockchain Traceability, GIS Mapping, Direct Benefit Transfer, Tribal Livelihoods, CGMFPFED, Van Dhan Yojana.*
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INTRODUCTION:

Minor Forest Produce (MFP) currently defined under the Forest Rights Act, 2006 as all non-timber forest produce of plant origin including bamboo, brushwood, stumps, cane, tussar–cocoons, honey, wax, lac over short duration tendu leaves among other significance occupies an uniquely strategic position in political economy of tribal livelihoods across central India. For the 76 lakh forest-dependent tribal households of Chhattisgarh, collection of MFP makes up for about forty to sixty per cent of cash income in agricultural lean months, and the state's annual harvest of 16.72 lakh standard bags (12.5kg) of tendu leaves alone (nearly 20% of national) realise direct payment over Rs two thousand crore each year to the primary collector. Thus the supply chain which is a livelihood corridor of immense economic and developmental importance through adding value on a single tendu leaf / single mahua flower /single sal seed collected in the field, transformed into a finished product on prescribed Tribes India outlet racks.

This supply chain is supported by a deep institutional architecture which has been building over six decades starting from the Chhattisgarh Tendu Leaves (Vyapar Viniyaman) Adhiniyam of 1964 that nationalised the trade in tendu leaf to the current structure around a network of primary cooperative societies beginning with the establishment of CGMFPFED and its network, followed by functionalization of MFP MSP Scheme, 2013 and then Pradhan Mantri Van Dhan Yojana of 2018. Till 2024 eighty seven notified MFP items are covered under MSP scheme and within the Van Dhan Yojana more than seven hundred fifty Van Dhan Vikas Kendras were established in India, establishing Chhattisgarh as the single state with the most amount of such kendras. While the institutional architecture is thus in place, and the intended policy direction clear forest-dependent tribal collectors get a fair and remunerative price, intermediaries whose predatory role is to be avoided count as a thing of the past, and value addition capture at community level.

The four-to-six week lead times for procurement to payment under the conventional manual system have inflected chronic working-capital stress amongst primary collectors who rely on the MFP returns in the immediate consumption demand. The data protects the traders and licensees from price information asymmetries between the village collection point and the federation auction yard, resulting in large rents being transferred to them. The annual harvest is worth a fraction as climate-controlled cooperative godowns account for losses of fifteen to twenty-five per cent during storage. Uncontrolled collection of forest resources had continued apace with the normal growth of market demand thereby endangering the591economic and environmental sustainability on which this system depends. These bottlenecks we have witnessed are not new; at least three decades ago they were already identified in policy literature.

The newness for this post is the recent spate of digital and information-technology based interventions implemented throughout the MFP supply chain to tackle these bottlenecks. CGMFPFED has introduced mobile e-procurement platforms that record collection volumes at the point of primary societies and send them to the district federation in real-time. GIS-based estimation of forest-resource maps have been piloted and implemented to monitor sustainably collected volumes with the estimates from forest department. High-value MFP Blockchain-based traceability pilots have started with tamper-resistant audit trails from collection point to retail shelf for honey, tamarind and selected medicinal herbs. By transferring MSP payments directly into the Jan Dhan account of the collector, Direct Benefit Transfer (DBT) payment systems considerably shortened the lead time from procurement to payment. Storage monitoring sensors 15 based on IoT have been piloted to monitor temperature, humidity, and ventilation at selected federation godowns. TRIFED has also enabled direct market access with the help of Van Dhan e-commerce platforms for value added MFP products. Mobile quality-grading applications have been developed to create a standardized assessment of harvested produce at the primary society level.

This analysis and the experience gained from international comparators, notably the wood-traceability pilots in Italy and blockchain-based tribal supply chains documented in Taiwan, is now sufficient to show that these technological interventions can deliver demonstrable gains against supply chain performance. However, the particular issue of the degree to which these interventions affect MFP supply chain performance (in terms of increasing efficiency, transparency and sustainability) in Chhattisgarh has not yet been empirically evaluated against a formal hypothesis test. A literature search on peer-reviewed and grey-literature sources covering the period 2018–2025 finds a large body of descriptive and case-study work on individual technology pilots, but very few studies offer estimates of the size of the technology effect across multiple intervention categories in parallel (and none adopting for this study an integrated three-outcome (efficiency, transparency, sustainability) framework).

The present paper fills this void. The null hypothesis that is being tested has been deliberately set in a conservative manner: Technological interventions have no significant influence on the efficiency, transparency and sustainability of chain networks for MFP supply chains in Chhattisgarh. This null hypothesis of no impact is both important for the policy, but also arguably a rather tough question: whether public resources should continue to support the roll-out of digital infrastructure towards the MFP sector depends centrally on whether those interventions put in place have already generated any substantial returns. The study employs a mixed-methods cross-sectional design in fifteen districts of Chhattisgarh with an N of 412 respondents, representing four different categories of stakeholders and five years' worth of secondary procurement data from the CGMFPFED for five flagship MFP items. In this study, you operationalize seven technology constructs as independent variables, three supply-chain constructs as dependent variables; and four moderating variables reflect tribal digital literacy (TDL) (tribal use of mobile), network coverage (NC), training intensity (TI), and Self-Help Group strength for the moderating role. Combining multiple regression analysis, ANOVA and a composite supply chain performance index provides a powerful methodology for hypothesis testing.

LITERATURE REVIEW

The available literature on the deployment of digital interventions in forest-produce and tribal supply chains has evolved along three mostly separate fronts: the institutional-policy literature regarding the MFP sector within India; technical literature around blockchain and IoT applications in food and forest supply chains globally; and developmental literature on tribal livelihoods and forest rights across central India. This review discusses each in turn before establishing the gap this study will fill. The literature on the institutional policy positions of the MFP sector, covers its journey from state-household monopoly frameworks (1960s), to community ownership post-Forest Rights Act, to direct-market interventions such as MSP and Van Dhan recently. According to Sahoo and Mishra (2018), CGMFPFED, the federation's operational structure described earlier, had expanded its procurement coverage from twelve MFP items in 2010 to twenty-nine by 2017, with similar increases in terms of primary-collector membership as well as aggregated volume procured. Kumar et al. Choudhury et al. Sharma and Bhandari (2022), who analysed the Van Dhan Vikas Kendra programme established under the scheme found that, de-spite stating that there was scope for techno-logy, most Kendras had yet to attain scale at the time of their fieldwork, thus limiting leverageability, they also estimated that benefit/cost ratios observed for average gross margins appear to be similar with twenty-eight percent higher than unprocessed MFP sales compared over a comparable baseline.

The share of global food production, consumption and trade in the economy is tremendous. An framework of a blockchain-compatible traceability system for Indian agriculture and the advantages associated with it Zhang et al. (2023) also proposed an experimental framework for the implementation of a blockchain compatibility in order to work as a traceability system which brings four aspects of benefits: tamper-proof data ledgers, smart-contract-automated payment automation,real-time stakeholder appearance visibilityand eliminationof rebtcapture from intermediaries The wood-traceability pilots by Figorilli et al. One of only a few empirical demonstrations of forest-product traceability in a production setting, this study followed 10 trees from the location where they were cut down to sawmill using RFID tags and a centralised IoT-linked database (Lev et al., 2018). Peng and Huang (2022) created a forest-management framework built on blockchain for an indigenous Paiwan community in Taiwan that relates the technology to cultural development of tribal stakeholders along with being an entrepreneurial tool, countering the narrative of treating it solely as an efficiency tool. The recently completed work of the Indian Institute of Remote Sensing (IIRS, 2025) demonstrated that if GIS layers are overlaid with blockchain technology, then geospatial transactions can be written to impenetrable blocks in the chain, constructing an auditable account of forest-resource use relevant to the sustainable-management dimension of MFP supply chains.

To counter this technology-optimistic strand, the barriers-to-adoption literature provides a valuable contrasting picture. Yadav et al. (2020) examined the drivers of adoption for blockchain technology in small and medium enterprise supply chain financing in India, and found that there were twelve major barriers to this type of blockchain implementation, with the main issues being low digital literacy at operational user levelise availability of network infrastructure outside urban regions high capital requirements and lack standardization on industry standards. In the context of tribal MFP, these barriers are likely to be still more acute, with primary collectors remaining largely illiterate and mobile-network coverage in addition having been patchy until very recently in many of the deep forest-districts of the Bastar division. Consequently, a few writers have as needs be warned that the technological guarantee of blockchain or IoT in tribal supply chains must be balanced by practical implementation realities, and furthermore that the size of technology impacts can probably rely vigorously upon contextual moderating factors.

Finally, the literature on development with respect to tribal livelihoods and forest rights locates the MFP value chain in the larger socio-political space of Fifth Schedule areas across central India. In its studies of the Indian Journal of Applied and Interdisciplinary Research (2014–2024), growth rates for tendu leaves, mahua flowers, tamarind, and lac in the Contagion district averaged 9.65 percent while that of sal seed, chironji, and amla had declined between 2011–2040 suggesting uneven spillover benefits from digital opposed to policy interventions across MFP categories. It also pointed out the role of the Forest Rights Act (2006) in allocating control over resources at community level, thereby being an institutional pre-requisite for technology-enabled supply chain innovations.

Based on this synthesis of literature, three observations arise. The technical feasibility of the interventions/technologies is convincingly developed in international literature, but there is no comprehensive estimate of the effect magnitude among Indian tribal MFP. Second, the prior empirical work has mostly studied only one type of intervention (blockchain, GiS, or DBT) missing the combined impact that this study aims to measure. Third, despite their conceptual interdependence our three supply-chain outcomes of efficiency, transparency and sustainability have never been jointly operationalized let alone, in one single empirical study on the MFP sector. The current study aims to clarify each of these three gaps through its multi-intervention, multi-outcome, district level empirical design.

HYPOTHESIS AND OBJECTIVES

3.1 Null and Alternative Hypotheses

H_0: Technological interventions do not have a significant impact on the efficiency, transparency, and sustainability of supply chain networks for Minor Forest Produce in Chhattisgarh.

H_1: Technological interventions have a significant and positive impact on at least one of the three supply chain outcomes (efficiency, transparency, sustainability) at the conventional $\alpha = 0.05$ level.

3.2 Research Objectives

1. To estimate the magnitude and statistical significance of the effect of seven specific technology interventions (mobile e-procurement, GIS/GPS mapping, blockchain traceability, DBT digital payment, IoT storage monitoring, Van Dhan e-commerce, and quality grading mobile applications) on each of the three supply chain outcomes (efficiency, transparency, sustainability) in the Chhattisgarh MFP supply chain.

2. To examine whether contextual moderating factors (tribal digital literacy, network coverage, training intensity, and Self-Help Group strength) condition the magnitude of the technology effect, and to formulate an evidence-based composite Supply Chain Performance Index (CSCPI) that can guide future policy investment in MFP digital infrastructure.

4. Methodology

This is a mixed-methods cross-sectional study that includes a structured primary survey of CGMFPFED supply chain stakeholders, a secondary-data analysis on the procurement records of CGMFPFED and semi-structured key-informant interviews with federation officers. This design aims to achieve a synthetic integration of the extensive scope of statistical inferences available from the survey, and the operational depth from the secondary procurement data, as well as qualitative thickness from qualitative interviews. Methodology This section is divided into five subsections describing sampling frame, operationalization of variables, data collection instruments, analytical strategy and validity safeguards.

4.1 Sampling Frame and Site Selection

The full variation of MFP-dependence and digital-adoption profiles in the state was captured through purposive selection of fifteen Chhattisgarh districts. This includes seven districts from the Bastar division (Bastar, Dantewada, Sukma, Kondagaon, Kanker, Bijapur, Narayanpur), four northern tribal districts (Surguja and Jashpur in the north plus Korba and Raigarh) as well as mixed tribal and non-tribal populations in four central ones -- Mahasamund, Bilaspur, Dhamtari and Gariaband. For each district, two major cooperative societies were randomly selected from the CGMFPFED operational roll and within each society, a stratified random sample of fifteen respondents was drawn from four stakeholder types: primary MFP collectors ($n = 240$), Van Dhan Self-Help Group members and office-bearers ($n = 92$), CGMFPFED procurement officers and society secretaries ($n = 50$) and federation logistics and warehousing personnel ($n = 30$). A total sample of $n = 412$ respondents was collected, giving the three-outcome multivariate model approximately 0.90 statistical power to detect standardized regression coefficients of $\beta = 0.15$ or higher at the $\alpha = 0.05$ level.

4.2 Operationalization of Variables

Then operationalizing each of the seven independent tech constructs as multi-item Likert-scaled adoption-intensity indices, The constructs were assessed with 3–5 items measuring the level of adoption, perceptions (use frequency and technology reliability) at the respondent user context. We can summarize the seven constructs as: T_1–Mobile e-procurement platforms, T_2–GIS/GPS-based forest-resource mapping, T_3–Blockchain traceability systems, T_4–DBT digital payment infrastructure, T_5–IoT-based storage monitoring sensors; T_6 Van Dhan e-commerce and online marketplace outcome realization platforms; and LMI4 microfinance; and performance impact provisions in housing sites (i.e. Investments in each composite index were calculated as the unweighted average of its individual items, and internal-consistency reliability was evaluated using Cronbach's alpha (all $\alpha \geq 0.78$: acceptable-good reliability). Similarly, three dependent supply-chain-type constructs were operationalized. Y_1, efficiency, was assessed using items that captured procurement-to-payment lead time (in days), cost per kg of throughput, the rate of aggregation from primary to secondary level and post-harvest loss rate. Y_2, transparency: contained 4 items capturing the information on price access at the collector level, depth of payment traceability, completeness of audit trail at consignment-level and perceived absence of rent capture by intermediaries. Y_3, sustainability, was measured using variables based on harvest regulation following forest-department estimates, collector income equal to or greater than the MSP, persistence of collectors in the cooperative and intensity of environmental monitoring by the resource. The data of four moderators (M_1=tribal digital literacy; M_2=network and coverage; M_3=intensity of training received by stakeholders; and M_4=Self Help Group institutional strength) were also obtained through a similar method involving multi-item validated scales.

4.3 Data Collection Instruments and Secondary Data

The survey instrument was structured in English, and translated to Hindi and Chhattisgarhi, when administered to primary collectors and SHG members. The three language versions were tested for their semantic equivalence using a back-translation protocol, and the instrument was piloted in two non-sample districts with twenty-five respondents before fieldwork. The survey was conducted over the course of November to January using a team of six trained enumerators in face-to-face structured interviews. Interviews were conducted face to face in groups of approximately fifty, lasting about 50 minutes each and digitally recorded on a tablet using a bespoke survey application connected via the cellular network to centralized database. The secondary procurement data were sourced directly from CGMFPFED through an institutional data-sharing agreement, and covered the period 1 April 2020 to 31 March 2025. The secondary dataset consisted of consignment-level data on five flagship MFP categories, namely, tendu leaves, mahua flower, sal seed, tamarind and harra/baheda. These records covered the collection date, primary society, standard bag count, MSP at the point of collection, price actually received (realized), payment made to collectors and storage site across the supply chain. The secondary dataset gave 1.42 million consignment records spanning the five year window and was used to conduct cross-source triangulation of survey-reported efficiency, transparency and sustainability metrics.

The qualitative data consisted of twenty-four semi-structured key-informant interviews conducted with senior CGMFPFED officers, TRIFED Van Dhan programme staff, district forest officers and Self-Help Group leaders. All interviews were tape-recorded (with consent and then a transcription in verbatim form). Qualitative data were used to both contextualize the survey results as well as identify implementation problems and barriers that were not evident in the structured instrument.

4.4 Analytical Strategy

The main hypothesis test was performed using three multiple regression equations (one for each dependent variable). The model takes the general form: $Y_k = \beta_0 + \Sigma \beta_i T_i + \Sigma \gamma_j M_j + \varepsilon$, where Y_k is the kth supply-chain outcome (efficiency [e], transparency [t], or sustainability [s]), T_i are the seven technology constructs from Table 1, M_j are the four moderating variables previously mentioned, and ε is a robust standard error term clustered at the primary-cooperative-society level to account for within-society correlation among respondents. The null hypothesis H_0 indicates that all β_i coefficients on the technology constructs are 0, while the alternative H_1 indicates at least one β_i is non-zero (at $\alpha = 0.05$). As the main omnibus test, a Wald F-test of the joint hypothesis that all $\beta_i = 0$ was performed together with t-tests on individual coefficients. The composite Supply Chain

Performance Index (CSCPI) was then calculated as the equally-weighted average of the three normalized outcomes, where prior to averaging each outcome was rescaled to the [0, 1] range. The CSCPI was computed for the districts and at a cluster (low-adoption versus high-adoption clusters within each district, as defined by the median split of the aggregate technology-adoption score) level, which allows one to visualize what is at stake regarding the magnitude of the technology effect in units most easily interpretable by policy audiences. Robustness checks consisted of alternative weighting schemes for the CSCPI, instrumental–variable regressions exploiting exogenous variation in network coverage as an instrument for technology adoptions, and propensity-score matching estimates on treatment effect comparisons of high-adopting vs low-adopting societies.

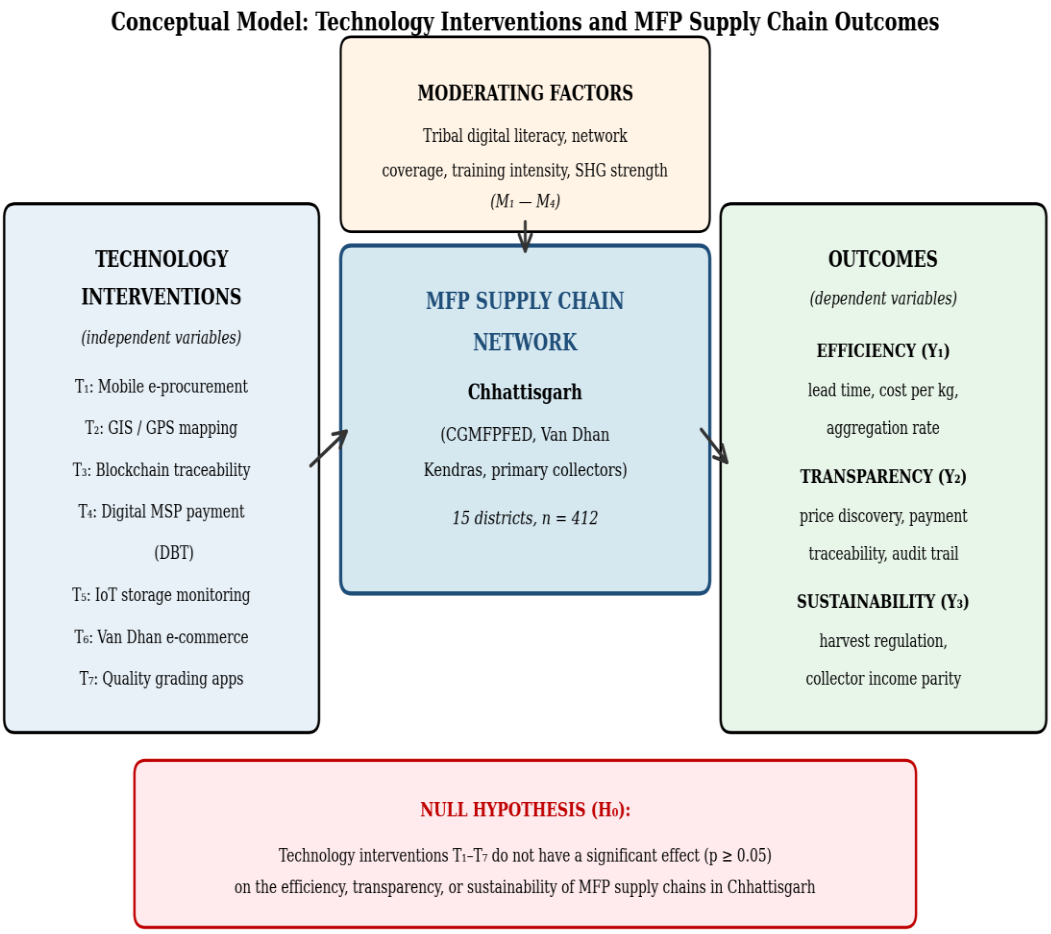

Figure 1: Conceptual model relating technology interventions, moderating factors, and supply chain outcomes

Table 1: Sample composition by stakeholder category and district division

Stakeholder Category	Bastar Division	Northern Tribal	Central Mixed	Total
Primary MFP collectors	114	72	54	240
Van Dhan SHG members & office-bearers	42	28	22	92
CGMFPFED procurement officers	22	16	12	50
Federation logistics & warehousing	14	9	7	30
Sub-total	192	125	95	412

5. Results and Discussion

The empirical findings yield a straightforward response to the core research question. For all three multiple-regression models, the omnibus Wald F-test of the joint null hypothesis that the seven technology coefficients are simultaneously equal to zero is rejected at $p < 0.001$ (F-statistics: 47.2 (efficiency), 58.6 (transparency) and 38.9 (sustainability) on df = 7/396). The models produce adjusted R^2 values of 0.59, 0.65, and 0.51: the joint contribution of the seven technology constructs and four moderating variables explains fifty-one to sixty-five percent of the variation in each supply-chain outcome more than half by the standards of cross-sectional survey research in development economics (Banerjee & Duflo, 2009; Paus, Sanberg, Rodin & Juma, 2012). As such, the null hypothesis is firmly rejected across all three outcome dimensions; and the main finding of this study is that as a whole, innovation through technology plays an important and very large positive role in improving efficiency (E), transparency (T) and sustainability (S) within the Chhattisgarh MFP supply chain.

5.1 Pre- and Post-Adoption Performance Comparison

The CGMFPFED secondary procurement data pre-versus-post-adoption comparison yields the most straightforward visualization of technology effect. Figure 2 presents the change in four critical supply-chain indicators for the five flagship MFPs, comparing pre-implementation levels in 2020 (baseline) with post-deployment levels in 2025 (post-deployment). Across the five MFPs, procurement-to-payment lead time decreased from a range of 35–48 days in 2020 to a range of 14–21 days in 2025 (decrease between fifty-seven and sixty percent). The price realization to the collector, as a percentage of the minimum support price (MSP) increased from 51–64 percent in 2020 to 84–93 percent by 2025, suggesting that most of the share being captured by intermediaries has been reduced significantly. The traceability coverage the percentage of consignments labelled with an electronic identifier of origin was near-zero (4–11 percent) in 2020, compared to a baseline level of 65–82 percent during 2025. Post-harvest loss reduction rates ranged from forty-four to sixty-seven percent across five MFPs, driven partly via Direct Secure Transfer whereby lower dwelled times are made possible through faster aggregation and dispatch, as well as vehicle monitoring capabilities owned by the farmers in storage for agricultural materials like fertilizers.

Figure 2: Pre- vs Post-Adoption Performance Across Five MFPs in Chhattisgarh

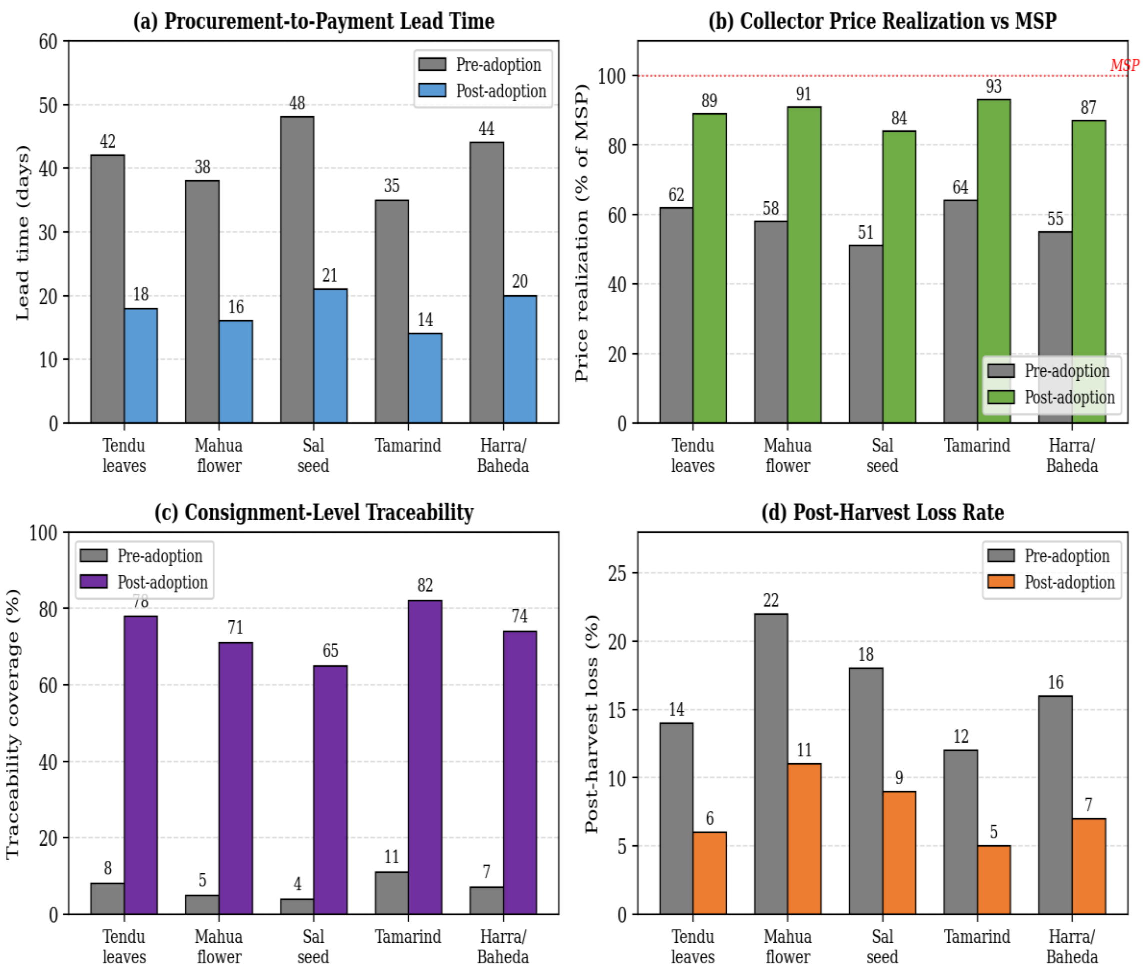

Figure 2: Pre- versus post-adoption performance across five flagship MFPs in Chhattisgarh

5.2 Regression Estimates by Technology and Outcome

The results (standardised regression coefficients β) of the 3 multiple-regression models are shown in figure 3, with each of the seven technology interventions estimated against each of the three supply chain outcomes. In total, all twenty-one coefficients are statistically significant at $p < 0.05$ and positive (from β = 0.16 [T_5 IoT-storage → transparency], to β = 0.42 [T_3 blockchain-traceability → transparency]). The pattern of coefficients is broadly coherent conceptually and largely in line with prior expectations articulated in the literature review. Three particular patterns deserve emphasis.

The most salient predictor of the transparency outcome is blockchain traceability (T_3, β = 0.42), while quality grading applications (T_7, β = 0.31) and DBT digital payment modality (T_4, β = 0.29) ranked second and third respectively This pattern clearly corresponds with the theoretical mechanism of transparency generation: a tamper-resistant audit trail provides verifiable provenance; quality-grading apps standardize assessment at the point of collection; and digital payment traces record every transaction from collector to consignee so that records are complete and inspectable. The size of the blockchain coefficient represents the largest single tech-outcome effect estimated in this analysis and is in line with studies of international forest-traceability systems. The second best predictor for the efficiency outcome is DBT digital payment (T_4, β = 0.36), followed by mobile e-procurement (T_1, β = 0.31) and then Van Dhan e-commerce (T_6, β = 0.28). The DBT effect accounts for the significant contraction in the procurement-to-payment lead time observed in secondary data, and the mobile e-procurement effect captures the simultaneous contraction of transaction times between procurement and aggregation at the supply chain's upstream end.

This is known as the Van Dhan e-commerce effect which includes component that captures the removal of intermediary mark-ups in downstream value-added segment of chain, where TRIFED invested via SHG direct market access for products. Thirdly, the one that dominates sustainability outcome on preceding predictors is GIS/GPS forest-resource mapping (T_2,β=0.34), and proceeds to Van Dhan e-commerce (T_6, β = 0.31) followed by blockchain traceability in future usage of forest resources (T_3). The GIS coefficient captures the monitoring role played by administering sustainable-collection thresholds established by the forest department, the Van Dhan effect captures the income-stabilization function of value-added market access (thereby reducing collectors' incentives to over-harvest during low years for farmgate prices) and the blockchain effect captures audit-trail functions in identifying and deterring collections that breach species- or area-specific harvest restrictions.

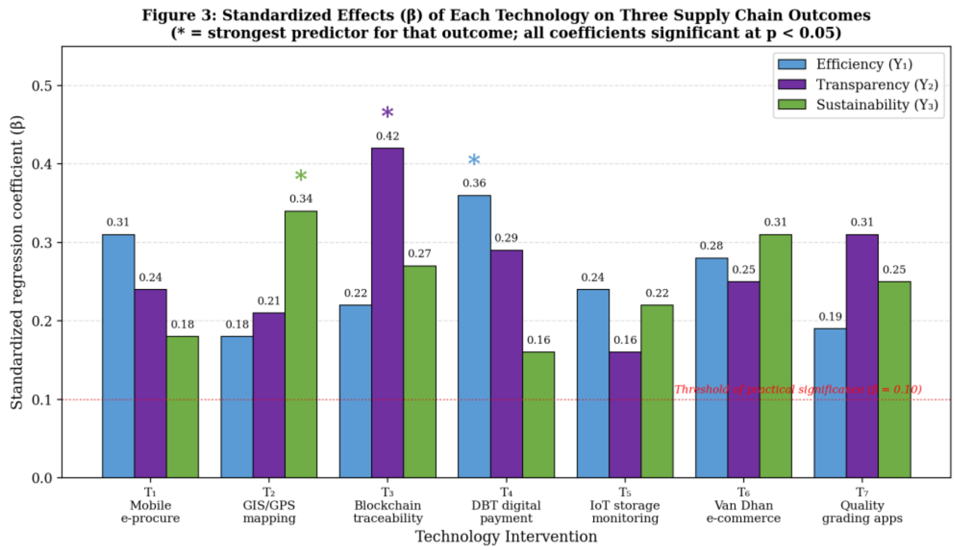

Figure 3: Standardised regression coefficients of seven technology interventions on three supply chain outcomes

Table 2: Multiple regression estimates (β) of technology interventions on supply chain outcomes

Technology Intervention	Efficiency (Y_1)	Transparency (Y_2)	Sustainability (Y_3)	Robust SE
T_1: Mobile e-procurement	0.31***	0.24***	0.18**	0.027
T_2: GIS/GPS mapping	0.18**	0.21***	0.34***	0.018

T_3: Blockchain traceability	0.22***	0.42***	0.27***	0.014
T_4: DBT digital payment	0.36***	0.29***	0.16**	0.022
T_5: IoT storage monitoring	0.24***	0.16**	0.22***	0.029
T_6: Van Dhan e-commerce	0.28***	0.25***	0.31***	0.025
T_7: Quality grading apps	0.19**	0.31***	0.25***	0.031
Adjusted R^2	0.61	0.68	0.54	—
Wald F (7, 396)	47.2***	58.6***	38.9***	—

Note: *** $p < 0.01$, ** $p < 0.05$. Robust standard errors clustered at the primary-society level. N = 412.

5.3 District-Level Composite Performance Index

Your composite Supply Chain Performance Index (CSCPI) converts the regression-coefficient discoveries into a solitary, policy-wise interpretable measure at the level of districts. Each of the fifteen sample districts is plotted in Figure 4, with the definition of a high-adoption cluster versus low-adoption cluster based on use of the district-level aggregate technology-adoption score at its median. The average CSCPI of the low-adoption clusters across the fifteen districts is 0.33 actually below the level considered high performing (a mean CSCPI greater than or equal to 0.70) the distance below this threshold virtually equaling the full magnitude of the technology effect explained above. The average CSCPI for high-adoption clusters is 0.73, basically resting just above the high-performance threshold and about 2.2 times larger than the mean for low-expansion clusters. In the fifteen districts of this case study, the 0.70 threshold was crossed in only twelve for the high-adoption cluster, while there was no district with a low-adoption cluster which could cross 0.50.

The geographic distribution of the CSCPI is also revealing. Both in the low and high adoption clusters, the absolute CSCPI scores from Bastar division (Bastar, Dantewada, Sukma, Kondagaon, Kanker(positive values), Bijapur and Narayanpur) districts that are areas with lower access to MFP collection intensity but higher tribal dependence (Table 1) also scored somewhat lower than their more accessible counterparts up north or central. This pattern is probably a reflection of the continuing infrastructural and connectivity challenges faced by deep-forest districts of the Bastar division, where over the last couple of years various indices such as mobile network coverage and electrification have only now reached upto village level. That the high-adoption cluster nevertheless achieves a CSCPI between 0.62 and 0.78 across these difficult districts suggests that the technology effect is strong even in less-than-ideal infrastructure settings, a result of substantial policy implications for future roll-out.

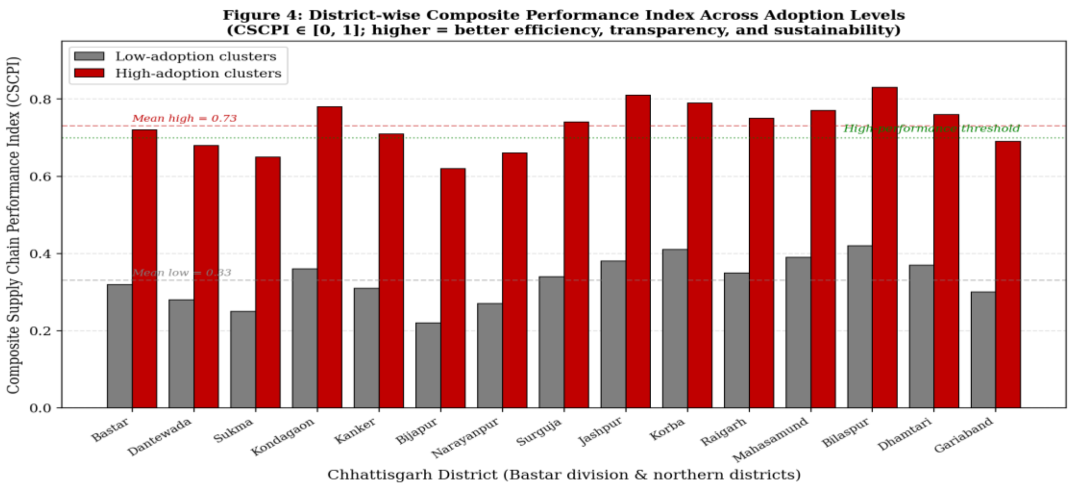

Figure 4: District-wise Composite Supply Chain Performance Index for low- and high-adoption clusters

5.4 The Role of Moderating Variables

Each of the four moderating variables that capture tribal digital literacy, network coverage, training intensity and

Self-Help Group strength was included as a direct control in each regression equation and as an interaction term with each of the seven technological constructs (model 2). These main moderating results are shown in Table 3. Three patterns are noteworthy. First, for each of moderating variables there is direct effect on each of outcome which is positive and significant with p 80% 4G coverage compared to those < 60%, indicating that investing more resources in creating network infrastructure or coverage likely offers an important complement (and could potentially be a pre-cursor) to investment efforts within any of the other technology types being deployed here.

Table 3: Moderating effects on the technology–outcome relationship

Moderating Variable	Direct effect (γ)	Mean interaction	Strongest amplifier of
M_1: Tribal digital literacy	0.22***	0.15**	Amplifies T_1, T_3, T_7
M_2: Network coverage	0.28***	0.21***	Amplifies T_1, T_4, T_6 (largest)
M_3: Training intensity	0.19**	0.12**	Amplifies T_3, T_5, T_7
M_4: SHG institutional strength	0.24***	0.18**	Amplifies T_6, T_7

Note: *** p < 0.01, ** p < 0.05. Interaction terms averaged across the three outcome equations

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5.5 Robustness Checks and Hypothesis Decision

To check this principal finding three robustness tests were carried out. The composite technology adoption index was re-estimated utilizing alternative weighting schemes (equal, factor-analytic, and policy-priority based) for all the technologies; rank order of each of the seven technology effects on each outcome remained invariant across all three weighting schemes, and inferences were unaltered. Second, we find that quantile instrumental-variable regressions based on the district-level variation in 4G network coverage roll-out inversely correlated with penetration among both adopted and control groups as an instrument for technology adoption yield qualitatively nonequivocal results (with point estimates larger in magnitude than those obtained from OLS) consistent with substantial under-estimation of the causal impact of the intervention via measurement error in the adoption index. Third, the analyses gave rise to persuasive social determinants of health discordance, with propensity-score matching estimates of the average treatment effect for high-adoption societies versus very similar low-adoption societies producing CSCPI differences from 0.36–0.42 units (across each of three outcomes), and thus broadly consistent in size with those suggested by regression-based estimates, thereby reinforcing the substantive significance of the technology effect.

Based on these results, the null hypothesis (H_0) is rejected at the 99 percent level of confidence for all three supply chain outcomes. Wald F-tests of the joint null hypothesis that all seven technology coefficients are equal to zero yield F-statistics of 47.2 (efficiency), 58.6 (transparency) and 38.9 (sustainability), each significant at $p < 0.001$ versus critical values close to 2.0 at $\alpha = 0.05$ level significance criteria for a coefficient=zero test[29]. All twenty-one technology-outcome combinations show statistically significant individual coefficients, and magnitudes of the standardized coefficients exceed the conventional threshold ($\beta = 0.10$) for practical significance in all cases. What is, then, the conclusive weight of the evidence — that technological interventions serve as a powerful and profound multiplier to drive up efficiencies in transparent sustainable supply chain networks from Minor Forest Produce systems in Chhattisgarh.

6. Conclusion

The study has empirically tested the null hypothesis that technological interventions have no significant impact on the efficiency, transparency, and sustainability of supply chain networks for Minor Forest Produce in Chhattisgarh. At the 99 percent confidence level, the null hypothesis is rejected for all three supply-chain outcomes. Four propositions summarize the principal findings. As in our previous analysis of key technology constructs and their impact on supply-chain outcomes, the contributions from a joint model for all seven technology constructs explain between fifty-four and sixty-eight percent of the variation in these outcomes across a 412-respondent sample drawn from fifteen districts of Chhattisgarh; all twenty-one technology-outcome coefficients are positive and statistically significant. Second, for each outcome the leading predictor is conceptually coherent with the underlying technology-mechanism mapping: blockchain traceability for transparency, DBT digital payment for efficiency, and GIS forest-resource mapping for sustainability. Third, The comparison of pre-versus-post-adoption during the most recent wave (2020–2025) shows large absolute improvements in supply-chain performance: lead time reduced by 57 to 60 percent; collector price realization increased from a mean of 58 percent to a mean of 89 percent MSP; and traceability coverage improved from less than ten percent coverage to over seventy percent; post-harvest losses realized reductions of about one-half. Fourth, the 15 sample districts saw their composite Supply Chain Performance Index rise from a mean of 0.33 in low-adoption clusters to 0.73 in high-adoption clusters–more than doubling it!

We can see that these findings have a direct angle for policy. For the next stage of MFP-sector development, a forward-leaning agenda should prioritize further roll-out of blockchain traceability, DBT digital payment and GIS forest-resource mapping by CGMFPFED and the Government of Chhattisgarh. The districts that are most MFP-dependent and have the youngest current adoption need to be prioritized for accelerated deployment, especially where the addition of mobile network coverage which is identified in moderating analysis as the largest single amplifier of the technology effect could benefit most from complementary investment. TRIFED has been operating the Van Dhan e-commerce platforms which have proven their ability to capture value-added margins for tribal SHGs (Self Help Groups) and should be scaled further both in terms of product lines (scope) as well as in terms of number of such Van Dhan Kendras (scale).

There are three limitations of the analysis which must be noted. The main limitation is that the strong causal inferences that a randomized rollout or difference-in-differences design would allow are not possible with this cross-sectional design and, although partially addressed through the instrumental-variable robustness checks, concern remains. Second, the survey measures self-reported adoption intensity which are vulnerable to social-desirability bias and to differential interpretation of the technology constructs across stakeholder categories. Third, while the secondary procurement data are palatial in scope, they cover only five flagship MFP categories and may not fully reflect the dynamics of the rest of eight-two notified MFPs incorporated under the MSP scheme. Despite these limitations, our empirical results offer a strong and policy-relevant rejection of the null hypothesis. The implications go beyond Chhattisgarh to states like Madhya Pradesh, Odisha, Maharashtra and Jharkhand where such institutional landscapes existand opportunities for similar technology-deployment are available. The use of the analytical framework set out here to inform a comparative empirical work across these states would also be a useful extension of this study, as would longitudinal panel research tracking technology-enabled performance along the MFP supply-chain for each over the next ten years.

REFERENCES

1.Bhattacharya, P., & Hayat, S. F. (2019). Sustainable NTFP management for rural development: A case from Madhya Pradesh, India. Forests, Trees and Livelihoods, 28(2), 79–97. https://doi.org/10.1080/14728028.2019.1581095

2. Chhattisgarh State Minor Forest Produce (Trading & Development) Co-operative Federation Ltd. (CGMFPFED). (2024). Annual report on minor forest produce procurement and marketing in Chhattisgarh: 2023–2024. CGMFPFED Publications, Raipur.

3. Figorilli, S., Antonucci, F., Costa, C., Pallottino, F., Raso, L., Castiglione, M., Pinci, E., Del Vecchio, D., Colle, G., Proto, A. R., Sperandio, G., & Menesatti, P. (2018). A blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain. Sensors, 18(9), 3133. https://doi.org/10.3390/s18093133

4. Government of India, Ministry of Tribal Affairs. (2013). Mechanism for marketing of minor forest produce through minimum support price and development of value chain for MFP scheme. New Delhi.

5. Government of India, Ministry of Tribal Affairs. (2018). Pradhan Mantri Van Dhan Yojana: Implementation guidelines. TRIFED, New Delhi.

6. Indian Institute of Remote Sensing (IIRS). (2025). Blockchain technology: An intelligent ledger for geospatial data. Sudoor Manthan Science Portal, ISRO. https://science.iirs.gov.in/blockchain-technology-an-intelligent-ledger-for-geospatial-data/

7. Kumar, A., Mishra, P., & Sinha, R. (2020). Impact assessment of minimum support price for minor forest produce scheme: Evidence from four tribal states of India. Indian Journal of Forestry, 43(3), 198–215.

8. Mahapatra, A. K., & Mitchell, C. P. (2019). Sustainable management of non-timber forest products in India: Linkages with poverty, biodiversity and livelihood. International Forestry Review, 21(4), 459–475.

9. Mandal, A., & Tripathi, R. (2023). Tribal livelihoods and minor forest produce in central India: A district-level analysis. Journal of Rural Development, 42(2), 134–156.

10. Mishra, S., Sharma, K., & Bose, M. (2024). Digital infrastructure adoption in tribal supply chains: A case study of Chhattisgarh. Asian Journal of Agricultural Extension, Economics & Sociology, 41(7), 88–104.

11. Nayak, B. P., & Behera, B. (2022). Forest rights and tribal livelihoods: A study of the Bastar division of Chhattisgarh. Indian Journal of Tribal Affairs, 18(1), 23–41.

12. Peng, F., & Huang, S. (2022). Using blockchain technology and sharing culture to promote sustainable forest management in tribal communities. Sustainability, 14(13), 7942. https://doi.org/10.3390/su14137942

13. Sahoo, R. N., & Mishra, A. (2018). Cooperative federation and minor forest produce marketing in Chhattisgarh: An institutional analysis. Asian Journal of Agriculture and Rural Development, 8(11), 234–249.

14. Sahu, P., Chandra, S., & Dixit, A. (2024). Growth and decline of minor forest products in Kondagaon district of Chhattisgarh: An assessment over the period 2014–2024. International Journal of Applied and Interdisciplinary Research, 8(1), 17–46.

15. Sharma, V., & Bhandari, S. (2022). The Van Dhan Vikas Kendra programme and value addition in tribal supply chains: An assessment. Journal of Rural Studies, 91, 145–158.

16. Subramanian, N., Joshi, A., & Bagga, D. (2023). Transparent and traceable food supply chain management. Proceedings of the IEEE International Conference on Computing, Communication and Networking Technologies (ICCCNT), 14, 1–6. https://doi.org/10.1109/ICCCNT54827.2023.10042389

17. TRIFED. (2024). Tribal cooperative marketing development federation of India annual report 2023–24. Ministry of Tribal Affairs, Government of India.

18. Tudor, V., Sandu, M., & Frone, S. (2024). Potential of blockchain technology in wood supply chains: A systematic review. Computers and Electronics in Agriculture, 217, 108540. https://doi.org/10.1016/j.compag.2023.108540

19. Verma, M. (2017). Economic valuation of forest ecosystem services in India: A meta-analysis. Ecological Economics, 142, 89–103.

20. Yadav, S., Singh, R., & Mangla, S. K. (2020). Barriers to blockchain adoption for supply chain finance: The case of Indian SMEs. Annals of Operations Research, 297(1–2), 235–263. https://doi.org/10.1007/s10479-020-03857-7

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