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Agricultural Technology, Functional Scale and Localized Value Creation: Pathways to Structural Transformation in Bihar, India

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Abstract

Agricultural transformation in developing agrarian economies depends not only on technological progress and increased productive capacity, but also on the capacity to deploy technological gains at economically viable scale and connect them with downstream value-adding activities. This study examines the role of functional scale in linking agricultural technological development with localized value-creation potential and broader structural transformation in Bihar, India. It develops a state-level analytical framework in which agricultural technology contributes to productive capacity and marketable output, while organizational and institutional arrangements influence the capacity to translate dispersed production into aggregation, processing, agrifood services, and wider economic transformation. Drawing on official state-level economic and agricultural statistics, the study finds that Bihar has a substantial and increasingly intensified agricultural production base. Cropping intensity increased from 147% in 2023–24 to 152% in 2024–25, while cereal production rose from 227.17 to 243.91 lakh tonnes. Indicators of functional-scale capacity also expanded: registered Farmer Producer Organizations increased from 221 in 2021 to 580 in 2024, and cumulative Custom Hiring Centres increased from 397 by 2019–20 to 832 by 2025. Downstream capacity is evidenced by 353 operational food-processing units and 12 operational ethanol units by September 2024. These observations demonstrate productive, institutional, and downstream capacity, but do not establish the proportion of agricultural value retained within Bihar. Localized value creation is therefore interpreted as an empirically supported potential and transformation pathway rather than a directly measured outcome. The study concludes that small ownership need not imply small-scale economic organization and that functional-scale institutions can provide an inclusive pathway for technology-enabled structural transformation.

Keywords: Agricultural technology; functional scale; localized value creation; land fragmentation; organizational scale; agrifood value chains; structural transformation; Bihar; India.

1. INTRODUCTION

Agriculture remains central to the development trajectory of low- and middle-income economies, not only as a source of food and employment but also as a potential foundation for wider economic transformation. Structural transformation has conventionally been associated with the movement of labour, capital, and economic activity from relatively low-productivity sectors towards more productive activities. Contemporary evidence, however, suggests that transformation cannot be understood simply as movement out of agriculture. Equally important is transformation within agriculture—from low-productivity and subsistence-oriented production towards technologically advanced, diversified, market-connected, and value-adding agrifood systems.

This issue is particularly relevant for India, where the movement of economic activity away from agriculture has progressed more rapidly than the reallocation of labour. Agriculture consequently continues to employ a disproportionately large share of the workforce relative to its contribution to aggregate output, contributing to persistent intersectoral productivity differentials [1]. An important development question therefore arises: can agricultural modernization itself become an active driver of

structural transformation by raising productivity, generating value-added activities, strengthening intersectoral linkages, and expanding more productive employment?

The answer increasingly depends on the developmental reach of technological change. Agricultural technology now extends beyond improved seeds, fertilizers, irrigation, and machinery to include climate-resilient practices, digital information systems, precision technologies, improved water management, remote sensing, artificial intelligence, and data-enabled decision-making [2]. These innovations can improve productivity and resource-use efficiency, but their broader developmental consequences depend on whether technological progress remains confined to primary production or stimulates higher-value activities throughout agrifood value chains.

The distinction between productivity growth and value creation is therefore fundamental. Higher agricultural output does not automatically generate proportionate increases in local incomes, employment, or structural transformation. Where commodities are marketed mainly as raw or minimally processed products, substantial downstream value may be generated elsewhere through storage, processing, packaging, transportation, branding, and associated services. Agricultural growth may consequently coexist with a deficit of localized value creation. By contrast, technological progress that strengthens the production-to-market continuum can generate backward and forward linkages and contribute more directly to structural transformation.

This problem is particularly important in Bihar, one of India's predominantly agrarian states. Bihar possesses substantial agricultural potential arising from fertile alluvial soils, diverse agro-climatic conditions, abundant labour, and opportunities for diversification across crops, horticulture, livestock, and fisheries. At the same time, agricultural development is constrained by small and fragmented operational holdings, uneven infrastructure, limited processing capacity, market imperfections, climate vulnerability, and continued dependence on relatively low-value primary production [27-29].

Land fragmentation is especially relevant because it affects the economics of technology adoption and participation in modern value chains. Small and fragmented holdings may limit investment in capital-intensive technologies, increase transaction and coordination costs, and constrain the economies of scale required for aggregation, storage, processing, and marketing [23,40]. The developmental consequences of technology therefore depend not only on technological availability but also on access to capital, infrastructure, markets, institutions, and mechanisms for collective organization.

Existing evidence nevertheless demonstrates the potential of technological change to improve agricultural performance in Bihar and Eastern India. Earlier research identified technological progress, mechanization, capital renewal, knowledge transfer, and improved production practices as important contributors to agricultural growth in Bihar [3]. Farm-level studies have similarly highlighted both the potential of modern technologies and persistent constraints affecting their adoption [4,5]. More recent Bihar-specific research demonstrates the importance of climate-resilient technologies, weather-based interventions, climate-smart practices, and conservation agriculture for improving productivity, resilience, and agricultural performance [6-9].

An important analytical gap nevertheless remains. Much of the existing literature examines technology adoption, productivity, climate resilience, or individual aspects of agricultural development separately. Comparatively less attention has been given to the structural relationship linking agricultural technology, localized value creation, and broader structural transformation, particularly in major subnational agrarian economies. Technology may increase productivity without generating substantial local value addition, while structural transformation may proceed without sufficiently strengthening productive activities within agriculture and the wider agrifood economy.

Bihar provides an important setting for examining this problem. The state combines substantial agricultural potential and evidence of technological and production change with persistent smallholder dominance, fragmented landholdings, limited agro-processing capacity, and significant labour out-migration. The resulting development challenge is therefore not simply whether Bihar can produce more, but whether it can convert agricultural productivity gains into economically diversified and locally retained value.

This study addresses that question by conceptualizing agricultural value addition as a principal transmission pathway between technological development and structural transformation. Agricultural

technology can raise productivity, increase marketable surpluses, improve product quality, and support diversification. These gains can create opportunities for aggregation, storage, processing, logistics, and other downstream activities, thereby strengthening agriculture-industry-services linkages and supporting employment diversification.

These relationships, however, are conditional rather than automatic. In Bihar, fragmented holdings and small operational units may constrain the conversion of productive capacity into value creation where technologies and downstream activities require economically viable scale. The central argument of this study is that these disadvantages need not be overcome exclusively through physical consolidation of land. Functional scale can instead be created through institutional and organizational arrangements—including Farmer Producer Organizations, collective action, coordinated production, secure land leasing, custom-hiring services, shared infrastructure, and improved market coordination [42-46]. Such arrangements can enable smallholders to obtain some of the economic advantages associated with larger-scale production and value-chain participation while retaining ownership rights.

The study therefore places functional scale at the centre of the relationship between agricultural technology and structural transformation. Its principal contribution is to distinguish physical landholding size from economically viable operational and organizational scale. Small ownership does not necessarily imply small-scale economic organization. Technological gains become more likely to generate localized value creation when dispersed production can be aggregated, coordinated, and connected with economically viable processing, marketing, and agrifood services.

The study makes three principal contributions. First, it develops an integrated analytical framework linking agricultural technological development, productive capacity, functional scale, localized value creation, and structural transformation. Second, it provides state-level evidence from Bihar, an important but comparatively underrepresented case in the literature on agricultural transformation in India. Third, it advances the concept of functional scale as an institutional mechanism through which the economic disadvantages of fragmented physical holdings may be reduced without requiring compulsory land consolidation.

The study is also distinct from the author's earlier work on agricultural value addition and economic linkages in Bihar [28]. While the earlier study examined the evolution and growth dynamics of agricultural value addition, the present analysis focuses specifically on the institutional and organizational conditions required to convert technological and productive gains into localized value creation in a fragmented smallholder economy.

The analysis is directly relevant to policy debates concerning agricultural modernization, food processing, rural industrialization, climate-resilient agriculture, digital agriculture, and higher-value rural employment. For Bihar, the strategic objective cannot simply be increased agricultural production. A more transformative pathway requires converting technological gains into sustained value creation through aggregation, diversification, processing, improved logistics, stronger market institutions, and deeper linkages between agriculture, industry, and services.

Against this background, the study addresses four interrelated questions:

1. To what extent has agricultural technological development contributed to productive capacity and value-creation potential in Bihar?
2. How can agricultural technological development contribute to broader structural transformation?
3. How do land fragmentation and related scale constraints affect the translation of productive gains into localized value creation?
4. What institutional mechanisms can create functional scale and strengthen technology-enabled structural transformation?

The remainder of the article is organized as follows. Section 2 develops the conceptual and theoretical framework. Section 3 describes Bihar's agricultural and structural context, data sources, variable construction, and empirical methodology. Section 4 presents the empirical results. Section 5 discusses the findings and their policy implications, particularly the role of functional scale in overcoming structural constraints. Section 6 concludes and identifies strategic pathways for technology-enabled localized value creation and structural transformation in Bihar.

2. CONCEPTUAL AND THEORETICAL FRAMEWORK

Agricultural transformation involves changes in technology, productivity, production systems, market participation, and the relationship between agriculture and the wider economy. More broadly, structural transformation refers to the reallocation of economic activity and employment towards relatively higher-productivity activities, accompanied by changes in technology, institutions, and intersectoral linkages [1,10-15]. Agriculture is therefore not merely a sector from which labour and resources eventually move elsewhere. Agricultural development can itself contribute to structural transformation through productivity growth, marketable surpluses, demand for industrial inputs, agro-processing, rural non-farm enterprises, and expanding agrifood services [10-15,18-20].

The developmental significance of agricultural modernization consequently cannot be assessed solely by increases in output or productivity. The more important question is whether technological and productive gains generate additional economic activity and locally retained value. The central proposition of this study is therefore that agricultural modernization becomes structurally transformative when technological and productivity gains are converted into sustained value creation, diversified economic activity, and stronger agriculture-industry-services linkages.

2.1. Agricultural Technology, Productive Capacity and Value Creation

Agricultural technological development includes improved seeds, irrigation, mechanization, climate-resilient technologies, conservation agriculture, digital information systems, and improved agronomic practices [2,5-9]. These innovations can increase productivity, cropping intensity, productive capacity, diversification, and product quality. Greater and more diversified output can, in turn, increase marketable surpluses and create opportunities for aggregation, storage, processing, logistics, and other value-adding activities.

The transformation pathway may therefore be summarized as:

Agricultural technology → higher productive capacity and diversification → greater marketable output → potential for value addition → agrifood linkages → structural transformation.

However, this sequence is not automatic. Technological progress may remain concentrated in primary production without generating proportionate downstream processing, employment, or locally retained value. Its wider developmental consequences depend upon complementary infrastructure, finance, institutions, market coordination, skills, and organizational capacity [14-20]. Technology should therefore be understood as an enabling rather than sufficient condition for structural transformation.

2.2. Agricultural Value Addition as the Transmission Pathway

Agricultural value addition represents the principal transmission pathway through which technological and productive gains can contribute to broader structural transformation. It includes activities that increase the economic value of agricultural commodities beyond primary production, including aggregation, grading, storage, processing, packaging, quality improvement, branding, logistics, marketing, and related agrifood services.

This distinction is particularly important for regional development. A region may produce substantial agricultural output while retaining only a limited share of the value generated along the wider commodity chain. Where commodities leave the producing region as raw or minimally processed products, downstream processing and associated services may develop elsewhere.

The relevant development objective is therefore not simply greater agricultural production, but:

More productive agriculture → greater locally retained value → stronger agrifood enterprises and services → broader structural transformation.

Contemporary research similarly emphasizes the importance of agrifood value chains, downstream employment, and rural non-farm activities in structural transformation [14,15,18-20]. The conversion of productive capacity into value addition, however, depends critically on whether agricultural production can be organized at an economically viable scale.

2.3. Land Fragmentation and the Problem of Functional Scale

Land fragmentation is a persistent characteristic of densely populated agrarian economies and may constrain investment, mechanization, coordination, and participation in scale-dependent value chains. Its effects should not, however, be interpreted as implying that small farms are inherently unproductive or incapable of technological adaptation. Evidence from Bihar demonstrates that technological adoption and improvements in agricultural performance are possible within predominantly smallholder production systems [3-9].

The more significant problem arises where technologies and downstream activities require substantial fixed investment, coordinated production, aggregation of large volumes, specialized infrastructure, or organized market participation. Under such conditions, small and fragmented holdings may increase transaction and coordination costs and make it difficult for individual producers to access machinery, storage, processing, grading, packaging, and organized markets [21].

The central analytical issue is therefore not simply farm size, but the capacity to achieve an economically viable scale of operation. This distinction provides the basis for the concept of functional scale, which constitutes the central contribution of the present study.

2.4. Functional Scale: The Central Analytical Contribution

Functional scale refers to the economically viable scale of technology use, production, aggregation, investment, processing, and market participation that can be achieved through institutional coordination and collective organization even when individual landholdings remain small or physically fragmented.

The concept distinguishes between physical scale and functional scale. Physical scale refers primarily to the size and spatial continuity of individual holdings. Functional scale refers to the effective economic scale created through collective action, coordinated production, aggregation, shared services, common infrastructure, institutional coordination, and integrated value-chain participation.

The central proposition is therefore:

Small ownership does not necessarily imply small-scale economic organization.

Farmers may retain individual ownership while collectively procuring inputs, accessing machinery, coordinating selected production activities, aggregating output, using shared infrastructure, and participating jointly in processing or marketing. The effective economic scale of these activities may consequently be substantially larger than that of any individual holding.

The Small Farmers Large Field approach provides an important illustration of this principle by enabling coordinated agricultural operations without requiring farmers to surrender ownership rights [38]. Research on collective action likewise demonstrates its importance for improving market access, reducing transaction costs, and strengthening smallholder bargaining power [36,37].

Accordingly:

Fragmented physical holdings + institutional coordination → functional scale.

Functional scale can then facilitate:

technology access + aggregation + investment + value-chain participation → localized value creation.

The concept should therefore be understood as an institutional and organizational mechanism capable of reducing, though not necessarily eliminating, the economic disadvantages associated with fragmented physical holdings.

2.5. Functional Scale as the Missing Link between Technology and Transformation

The relationship between agricultural technology and structural transformation is conditional rather than linear. Agricultural technology can increase productive capacity, but the conversion of that capacity into value addition depends substantially on functional scale, institutional capacity, infrastructure, and market coordination.

Conceptually:

$$VA = f(T, PC, FS, I, M, INF)$$

where VA represents agricultural value addition; T, technological development; PC, productive capacity; FS, functional scale; I, institutional capacity; M, market coordination; and INF, infrastructure.

Within this framework, functional scale acts as a central institutional mechanism influencing the transition:

Technology → productive capacity → value addition.

Where functional scale is weak, increased production may remain dispersed among numerous small producers, limiting economically viable aggregation and downstream investment. Where functional scale is stronger, producers may be better able to access capital-intensive technologies, reduce transaction costs, meet quality standards, aggregate output, utilize common infrastructure, and establish relationships with processors and organized markets.

The distinction is therefore between:

Technology adoption: Technology → higher productivity

and

Technology-enabled transformation: Technology + functional scale + institutions + infrastructure
→ value creation → structural transformation.

This distinction is central to the present study.

2.6. Institutional Pathways for Creating Functional Scale

Functional scale can be created through several complementary institutional mechanisms.

Farmer Producer Organizations (FPOs) and collective action can aggregate farmers' participation in input, technology, and output markets. Their potential functions include collective procurement, technology dissemination, machinery services, output aggregation, quality control, storage, primary processing, and collective marketing. Evidence from Bihar indicates that producer organizations can strengthen agricultural practices and market participation, although their effectiveness depends upon governance, managerial capacity, finance, and institutional support [36,37,43].

Coordinated production can similarly generate operational scale without eliminating individual ownership. Synchronization of selected agricultural operations, joint procurement, technology access, and collective marketing can create advantages for mechanization, quality standardization, aggregation, and market participation [38].

Secure and flexible land-leasing arrangements can increase operational scale through voluntary consolidation while preserving underlying ownership rights. Research on India indicates that imperfections and restrictions in land rental markets can impede efficient resource allocation [39-41]. The objective should therefore be transparent and secure voluntary arrangements rather than compulsory consolidation.

Finally, shared technology and infrastructure services can enable smallholders to access capital-intensive technologies without individual ownership. Custom-hiring centres, machinery pools, FPO-managed equipment, and private service providers can improve access to mechanization and related services at economically viable costs. This shifts the policy emphasis from technology ownership towards effective technology access.

2.7. From Functional Scale to Localized Value Creation and Structural Transformation

The ultimate developmental significance of functional scale lies in its capacity to connect dispersed agricultural production with downstream economic activities. The transformation process can be summarized as:

Dispersed production → coordinated production and aggregation → economically viable volumes
→ storage and processing → market integration → greater localized value retention.

Functional scale thus provides the missing institutional connection between agricultural modernization and localized value creation. It can support agrifood processing, enterprises, logistics, business services, and other activities requiring volumes, coordination, investment, and market integration.

This perspective also supports a more inclusive interpretation of structural transformation. Transformation need not consist solely of labour leaving agriculture. It can also involve movement from relatively low-value primary production towards higher-productivity activities within and around

agrifood systems, including machinery services, input supply, aggregation, storage, processing, transportation, packaging, quality testing, marketing, and digital and business services [15,18,20].

For Bihar, therefore, agricultural transformation should not be interpreted simply as reducing the importance of agriculture. The strategic objective is to use a stronger agricultural base as a foundation for expanding higher-value activities and strengthening agriculture-industry-services linkages.

2.8. Integrated Framework and Analytical Propositions

The integrated conceptual framework is presented in Figure 2.1 and generates the following propositions:

Proposition 1. Agricultural technological development contributes to higher productive capacity and greater marketable agricultural output.

Proposition 2. Higher productive capacity creates the potential, but does not automatically ensure, increased localized agricultural value addition.

Proposition 3. Land fragmentation and small operational holdings can constrain the conversion of productive capacity into value creation where technologies and downstream activities require substantial economic scale.

Proposition 4. Central Proposition. Functional scale created through collective and institutional arrangements can reduce the economic disadvantages associated with fragmented physical holdings and strengthen the translation of technological and productive gains into localized value creation.

Proposition 5. Greater localized agricultural value addition can strengthen agrifood industrial and service linkages, thereby contributing to employment diversification and broader structural transformation.

Because the present study relies primarily on state-level aggregate evidence, these propositions are interpreted as an integrated analytical framework supported by observed structural patterns and theoretical evidence rather than as separately identified causal effects.

2.9. Distinction from the Author's Earlier Study

The framework also distinguishes the present manuscript from the author's earlier study of agricultural value addition and economic linkages in Bihar [28]. The earlier research examined the evolution and growth dynamics of agricultural value addition. The present study advances the analysis by focusing on the institutional and organizational conditions required to convert technological and productive gains into localized value creation in a fragmented smallholder economy.

The progression is therefore:

Earlier study: Agricultural growth → value addition and economic linkages → development outcomes

Present study: Agricultural technology → productive capacity → functional scale → localized value creation → agrifood linkages → structural transformation

The distinctive contribution of the present manuscript is thus the proposition that technological progress does not become structurally transformative automatically. Its developmental effects depend critically on the capacity to create functional scale through collective, institutional, and organizational arrangements capable of converting dispersed agricultural production into economically viable value creation.

3. DATA, ANALYTICAL APPROACH AND METHODOLOGY

3.1. Bihar as the Empirical Context

Bihar provides an important setting for examining the relationship among agricultural technological development, productive capacity, localized value creation, and structural transformation. The state has fertile alluvial land, diverse agro-climatic conditions, and substantial potential across crops, horticulture, livestock, fisheries, and other allied activities. Agriculture consequently remains central to employment, livelihoods, food security, and the rural economy [25-27].

At the same time, agricultural production is predominantly organized through small and fragmented operational holdings [35]. This structure does not prevent intensification or technological improvement, but it can constrain activities requiring substantial fixed investment, coordinated production, aggregation, storage, processing, and organized market participation.

The central empirical issue is therefore not simply whether Bihar has increased agricultural production, but whether improvements in productive capacity are being translated into locally retained value and wider economic transformation. The analysis examines the following broad pathway:



The realization of this pathway is conditioned by land fragmentation, infrastructure, finance, processing capacity, market coordination, and institutional capacity. Particular attention is therefore given to functional scale—the capacity to achieve economically viable operational scale through collective and institutional arrangements without necessarily consolidating land ownership.

3.2. Data Sources and Empirical Scope

The study is based primarily on secondary data from official and publicly accessible sources. Bihar-level information is drawn principally from the Directorate of Economics and Statistics, Government of Bihar; Bihar Economic Survey; State Income Estimates; Bihar Statistical Profile; agricultural statistics; the Bihar State Data Lab and e-Statistics Portal; and the Fourth Agriculture Roadmap [25-33].

National agricultural and structural information is supplemented, where necessary, by publications of the Department of Agriculture and Farmers Welfare and other Government of India sources [34,35].

The analysis uses the longest reasonably consistent annual series available for the principal indicators. Because data availability differs across agricultural and economic variables, a common period is not artificially imposed where this would substantially reduce the available evidence.

The state-level approach is appropriate because the study investigates Bihar's broader transformation trajectory rather than individual farm or district behaviour. Its findings should therefore be interpreted as evidence on structural trends and empirical associations rather than definitive causal effects at the farm, enterprise, or value-chain level.

3.3. Analytical Dimensions and Variable Construction

The empirical framework integrates four principal dimensions:

1. Agricultural technological and productive development;
2. Agricultural productive capacity and marketable output;
3. Agricultural value addition and localized value-creation potential; and
4. Structural transformation.

A fifth dimension—functional scale and institutional coordination—is incorporated as a structural conditioning mechanism because consistent annual state-level indicators are not available for direct econometric measurement.

3.3.1. Agricultural Technological and Productive Development

Agricultural technological development includes improvements in seeds, irrigation, mechanization, agronomic practices, climate-resilient technologies, digital applications, and related innovations [2-9]. No single state-level indicator adequately captures this multidimensional process.

The analysis therefore uses observable indicators associated with agricultural modernization and productive transformation, including agricultural productivity, cropping intensity, irrigation development, production growth, and changes in crop composition. These indicators are interpreted primarily as measures of productive capacity and intensification, rather than as direct measures of technology adoption.

This distinction avoids mechanically attributing all improvements in agricultural performance to technology alone, since productive outcomes may also reflect infrastructure, institutions, climatic conditions, and changing farming practices.

3.3.2. Productive Capacity and Marketable Output

The second-dimension concerns Bihar's capacity to generate agricultural production capable of supporting downstream economic activities. The analysis examines changes in cropping intensity, production, productivity, diversification, and the scale of major agricultural and allied activities.

Higher productive capacity can provide the raw-material base for aggregation, storage, processing, packaging, logistics, marketing, and associated services. However, production growth does not automatically ensure that these activities develop within the producing region.

The analysis therefore distinguishes between:

1. productive capacity, which creates opportunities for value addition; and
2. realized localized value creation, which depends upon complementary infrastructure, investment, institutions, and market coordination.

3.3.3. Agricultural Value Addition and Localized Value Creation

Agricultural value addition constitutes the principal transmission mechanism in the proposed transformation pathway. It includes economic activities that increase the value of agricultural products beyond primary production, including aggregation, grading, storage, processing, packaging, logistics, marketing, and related services.

Consistent state-level annual measures of all downstream activities are not available. The analysis consequently distinguishes between directly observable indicators of agricultural economic performance and the broader potential for localized value creation arising from Bihar's agricultural production base.

Importantly, the study does not assume that high agricultural production necessarily implies high local value capture. Rather, the gap between productive capacity and realized downstream value creation constitutes a central empirical and developmental issue.

3.3.4. Structural Transformation

Structural transformation is examined primarily through changes in the sectoral composition of Bihar's economy, particularly the shares of agriculture, industry, and services in Gross State Value Added (GSVA).

A declining agricultural share is not interpreted as agricultural decline. Structural transformation may occur alongside agricultural modernization and productivity growth when economic activity expands towards industry, services, agrifood processing, and rural non-farm activities.

Accordingly, the analysis interprets structural transformation as involving both:

1. modernization and productivity improvement within agriculture; and
2. diversification towards higher-value industrial, service, and agrifood activities.

3.3.5. Functional Scale and Institutional Coordination

Functional scale represents the distinctive institutional dimension of the study. It is operationalized empirically as the capacity of institutions and shared-service arrangements to aggregate producers, provide access to indivisible or capital-intensive technologies, coordinate transactions, and support downstream market participation. Because no single official annual series measures functional scale

directly, the study uses a transparent proxy bundle rather than claiming to observe the latent concept itself.

Three observable proxy families are used. First, collective-organization capacity is represented by the number of registered Farmer Producer Organizations (FPOs) under the national FPO formation and promotion framework. Second, shared-technology and operational-scale capacity is represented by Custom Hiring Centres (CHCs), which are explicitly designed to overcome the diseconomies of individual machinery ownership associated with small holdings. Third, downstream value-chain capacity is represented by observable food-processing and agro-processing activity, including operational food-processing units, food-processing investment, sugar processing, ethanol production, and related infrastructure. These indicators capture enabling conditions for functional scale rather than the complete concept.

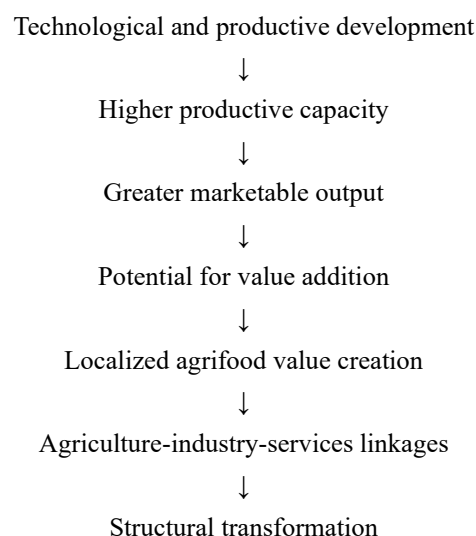
For comparability, FPO and CHC counts are also expressed relative to the 16.413 million operational holdings recorded in the 2015-16 Agricultural Census. This denominator is used only as a fixed structural benchmark because a later complete state-wide census of operational holdings is not available. The resulting densities should therefore be interpreted as institutional-capacity indicators relative to the latest comprehensive holdings benchmark, not as current per-farmer coverage rates. FPOs under the relevant national scheme increased from 221 in 2021 to 356 in 2022 and 580 in June 2024, equivalent to an increase of approximately 162% between 2021 and 2024. CHCs increased from a cumulative 397 by 2019-20 to 685 by 2023 and 832 by 2025. The evidence consequently permits functional scale to be examined as an observable institutional capacity rather than as an entirely abstract construct.

These proxies do not measure whether a particular FPO or CHC actually aggregates output, lowers transaction costs, raises producer prices, or increases local value capture. They are therefore treated as enabling proxies. The empirical interpretation is deliberately limited to whether the expansion of such institutions is temporally consistent with Bihar's productive and structural changes. No causal effect of FPOs, CHCs, or other institutional arrangements is inferred.

3.4. Integrated Analytical Approach

The study combines descriptive and structural analysis, trend examination, sectoral analysis, proxy-based assessment of functional-scale capacity, and exploratory association checks using the longest consistently available state-level series. The empirical strategy is deliberately modest because the principal institutional proxies are available only for selected years and are not sufficiently homogeneous to support a conventional multivariate time-series model. The analysis therefore distinguishes three levels of evidence: (i) directly observed agricultural and structural outcomes; (ii) observable institutional proxies for functional scale; and (iii) commodity-specific downstream indicators that document value-adding activity but do not measure total local value retention.

The analytical sequence follows the conceptual framework:



The analysis first examines evidence of agricultural productive transformation. It then examines observable proxies for functional scale and their temporal correspondence with productive and structural outcomes, followed by commodity-specific evidence of downstream processing and changes in Bihar's sectoral economic structure. The analysis does not treat temporal co-movement as proof of causality and does not infer local value retention from production alone.

3.5. Operationalization of Functional Scale and Exploratory Association Analysis

The concept of functional scale is operationalized through observable institutional and operational proxies. The principal proxy is collective-organization capacity, measured by registered FPOs; a second proxy is shared-mechanization capacity, measured by CHCs. These proxies are complemented by downstream processing indicators to distinguish enabling institutional capacity from realized value-adding activity.

The FPO series available for Bihar records 221 registered FPOs in March 2021, 356 in March 2022, and 580 in June 2024. The CHC evidence records 397 cumulative centres by 2019-20, 685 by October 2023, and 832 by the latest 2025 reporting point. Relative to the 16.413 million operational holdings recorded in the 2015-16 Agricultural Census, the corresponding FPO densities rise from approximately 13.5 to 21.7 and 35.3 FPOs per million holdings, while the CHC benchmark rises from approximately 24.2 to 41.7 and 50.7 centres per million holdings over the available reporting points. These ratios are structural benchmarks, not current coverage rates. [31,45,46].

To examine association with structural transformation, an exploratory bivariate check was undertaken using the available matched observations for CHC stock and the agriculture share of GSVA. For the early period in which annual CHC establishment data are consistently available (2014-15 to 2019-20), the cumulative CHC stock is compared with Bihar's agriculture-and-allied GSVA share. The Pearson correlation is approximately 0.16 ($n=6$), indicating no robust linear association in this short early-period series. This result is not interpreted as evidence against the functional-scale proposition: the proxy captures only one mechanism, the series is short, and downstream value capture is not represented by the dependent variable. [26,46].

A second, later-period descriptive comparison uses the nearest available CHC stock observations—397 by 2019-20, 685 by 2023 and 832 by 2025—and the corresponding recent agriculture GSVA shares reported by official sources. The decline in agriculture's relative GSVA share occurs alongside expansion of the CHC stock, but the observation count is too small and the dates are not perfectly synchronized for an inferential regression. It is therefore reported as directional co-movement rather than a statistical causal test. [26,46].

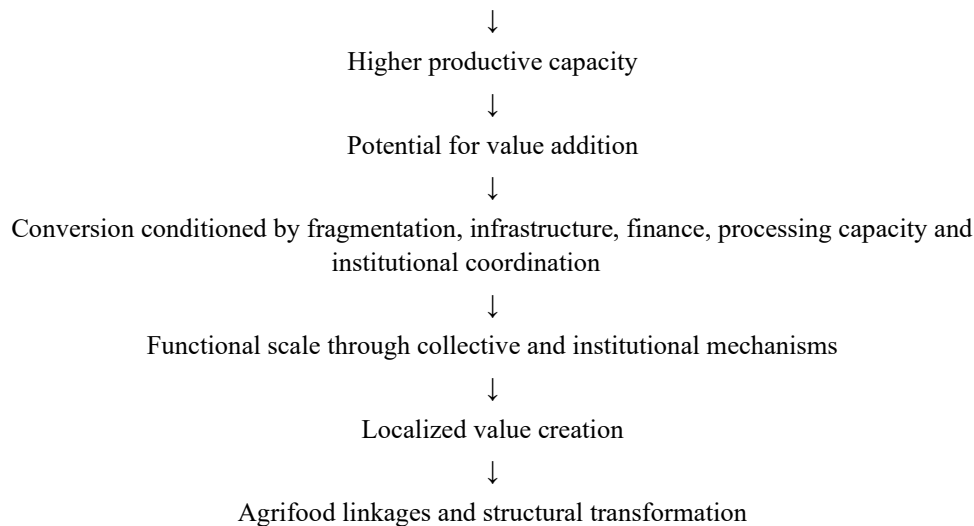
For value creation, the analysis uses observable downstream indicators rather than attempting to construct an artificial monetary measure of local value retention. By September 2024, Bihar reported 353 operational food-processing units with total investment of ₹3,517.09 crore and 12 operational ethanol units with investment of ₹1,363.38 crore. In 2023-24, nine sugar mills crushed 677.20 lakh quintals of sugarcane and produced 68.77 lakh quintals of sugar, with associated distillery capacity of 530 kilolitres per day. These indicators demonstrate that downstream processing is occurring within Bihar and therefore provide evidence beyond simple agricultural production; however, they do not reveal the share of commodity-chain value accruing to Bihar's producers, processors, workers, or firms. [26].

The empirical strategy therefore answers the measurement concern in a bounded manner: functional scale is no longer treated as wholly unobservable, because its principal institutional manifestations are proxied by FPO and CHC capacity; and localized value creation is no longer inferred solely from production, because downstream processing indicators are explicitly examined. At the same time, the study does not claim to identify a causal coefficient or a percentage of value retained locally that the available data cannot support.

3.6. Analytical Interpretation of Functional Scale

Functional scale is incorporated through a conditional transformation framework. The revised framework treats functional scale as an observable institutional capacity that conditions, rather than mechanically determines, the conversion of productive capacity into downstream value-adding activity.

Agricultural technological development



The proxy framework does not imply that fragmented holdings prevent agricultural modernization. Bihar's productive capacity itself demonstrates that smallholders can participate in technological change. The central issue concerns whether dispersed production can access the organizational and shared-service arrangements required for aggregation, processing, investment, and organized market participation.

Functional scale is therefore interpreted as an institutional capacity that can reduce some economic disadvantages associated with physical fragmentation. The observable proxies provide evidence that such capacity has expanded, but they do not establish that every FPO or CHC is commercially effective or that expansion has caused downstream value creation.

The principal mechanisms include FPOs, collective procurement and marketing, shared technological services, custom-hiring centres, voluntary land leasing, coordinated production, aggregation centres, and common storage or processing facilities. The empirical analysis treats these as pathways through which functional scale may operate, rather than as individually identified causal treatments.

3.7. Methodological Limitations

The findings should be interpreted within several limitations.

First, the analysis is based primarily on aggregate state-level data and therefore identifies structural trends and exploratory associations rather than definitive causal effects.

Second, substantial heterogeneity exists across Bihar's districts, commodities, farming systems, and farm-size categories that cannot be fully captured at the aggregate level.

Third, agricultural technology is multidimensional, and productive indicators should not be interpreted as direct measures of technology adoption.

Fourth, the functional-scale proxies are incomplete: FPO and CHC counts measure institutional availability or stock, not utilization, governance quality, turnover, service intensity, or the volume of output actually aggregated.

Finally, direct measurement of the proportion of agricultural value retained locally through processing, logistics, marketing, and associated services remains constrained by the absence of integrated commodity-level value-chain accounts. The downstream indicators used here demonstrate realized processing activity, but they cannot be converted into a statewide value-retention rate without additional enterprise- and commodity-level data.

These limitations define the appropriate scope of inference. The revised analysis therefore treats functional scale as a measurable but imperfect institutional construct and localized value creation as a combination of observable downstream activity and a broader value-retention proposition that remains incompletely measured at state level.

The findings are consequently interpreted as evidence on structural relationships, proxy-based institutional capacity, and analytically plausible transformation pathways, rather than as definitive causal estimates.

4. EMPIRICAL RESULTS: AGRICULTURAL PRODUCTIVE CAPACITY, FUNCTIONAL SCALE AND STRUCTURAL TRANSFORMATION IN BIHAR

4.1. Overview of the Empirical Findings

This section examines whether observable state-level evidence from Bihar is consistent with the transformation pathway proposed in Section 2 and whether measurable proxies of functional-scale capacity add empirical content to the central proposition.

Agricultural technological development → productive capacity → marketable output → value-addition potential → functional scale → localized value creation → agrifood linkages → structural transformation.

Four broad findings emerge. First, Bihar possesses substantial agricultural productive capacity despite the predominance of small and fragmented holdings. Second, observable institutional proxies show an expansion of collective-organization and shared-mechanization capacity. Third, downstream processing activity is substantial enough to demonstrate realized value-adding activity, although its share of total agricultural value and the portion retained locally cannot be calculated from the available data. Fourth, the state economy is undergoing gradual structural diversification, with industry and services increasing their relative contributions to GSVa.

The evidence therefore distinguishes between productive capacity, functional-scale capacity, and realized value-adding activity. Large agricultural output creates opportunities for processing, storage, logistics and related services; institutional proxies indicate increasing capacity to organize production and access shared technology; and commodity-specific evidence confirms that some downstream processing occurs within Bihar. The available evidence nevertheless does not establish a causal chain from functional scale to local value retention.

4.2. Agricultural Productive Capacity and Marketable Output

Bihar's agricultural system demonstrates considerable productive intensity despite limited scope for expanding cultivated land and the predominance of small operational holdings. Cropping intensity increased from 147% in 2023-24 to 152% in 2024-25, indicating intensive utilization of agricultural land and substantial productive capacity [26,31,32].

Cereal production also increased from 227.17 lakh tonnes in 2023-24 to 243.91 lakh tonnes in 2024-25, an increase of approximately 7.4%. In 2024-25, Bihar produced approximately 99.34 lakh tonnes of rice, 78.27 lakh tonnes of wheat and 66.03 lakh tonnes of maize [31,32]. Thus, the 7.4% figure refers to cereal production, not cropping intensity.

Table 4.1. Selected indicators of agricultural productive capacity in Bihar

Indicator	2023-24	2024-25	Interpretation
Cropping intensity (%)	147	152	Increased productive intensity
Cereal production (lakh tonnes)	227.17	243.91	Expanded production base
Rice production (lakh tonnes)	—	99.34	Major processing potential
Wheat production (lakh tonnes)	—	78.27	Large marketable output
Maize production (lakh tonnes)	—	66.03	Potential for feed and processing
Commercial crops (lakh tonnes)	138.39	123.13	Significant commodity base

Source: Compiled from official Directorate of Economics and Statistics, Government of Bihar, and e-Statistics data [26,31,32].

These indicators support Proposition 1: Bihar has developed substantial productive and marketable agricultural capacity. However, productive growth should not be equated automatically with localized

value creation. Production provides the material base for transformation, but does not itself demonstrate that downstream value is retained within the state.

4.3. Productive Capacity and Potential for Localized Value Creation

The scale of Bihar's agricultural production provides a substantial foundation for downstream activities. Rice, wheat, maize, sugarcane and other commodities can support aggregation, storage, processing, packaging, transportation, branding and related business services.

Table 4.2. Major production and illustrative value-chain opportunities, 2024-25

Commodity	Production	Illustrative opportunities
Rice	99.34 lakh tonnes	Milling, packaging, storage and branding
Wheat	78.27 lakh tonnes	Flour milling and food processing
Maize	66.03 lakh tonnes	Feed, starch, food processing and ethanol
Sugarcane	121.50 lakh tonnes	Sugar, ethanol and bioenergy
Jute	1.37 lakh tonnes	Fibre processing and diversified products
Total cereals	243.91 lakh tonnes	Storage, processing, logistics and marketing

Source: Directorate of Economics and Statistics, Government of Bihar; e-Statistics Portal [31,32].

The evidence in this subsection now distinguishes three levels: production, downstream processing activity, and local value retention. Production statistics establish the raw-material base; processing and agro-industrial indicators establish that some value-adding activity occurs within Bihar; but neither source establishes the proportion of total commodity value retained in the state.

Commodity-specific downstream evidence strengthens the empirical basis for the value-creation discussion. Bihar reported 353 operational food-processing units with aggregate investment of ₹3,517.09 crore as of September 2024. Ethanol production included 12 operational units with investment of ₹1,363.38 crore. In sugarcane processing, nine sugar mills crushed 677.20 lakh quintals of sugarcane in 2023-24 and produced 68.77 lakh quintals of sugar, with associated distillery capacity of 530 kilolitres per day. These observations demonstrate realized downstream processing and agro-industrial activity rather than merely hypothetical potential.

The empirical distinction is therefore:

The last transition remains incompletely measured because the available state-level data do not identify the distribution of value among producers, processors, traders, logistics providers, workers and other actors. The study therefore treats localized value creation as an empirically grounded pathway with partial downstream evidence, not as a fully quantified outcome.

This supports Proposition 2. Bihar clearly possesses a large production base, but the conversion of this base into processing, logistics, branding and other downstream activities depends upon infrastructure, investment, market coordination and institutional organization.

4.4. Functional Scale as the Link between Production and Value Creation

The central empirical issue is therefore not simply the size of Bihar's agricultural production, but the scale at which production and downstream activities can be economically organized.

Bihar's agriculture consists predominantly of numerous small and fragmented operational holdings [35]. The revised proxy analysis shows that institutional mechanisms intended to overcome scale constraints have expanded alongside this structure. Registered FPOs under the national scheme increased from 221 in 2021 to 356 in 2022 and 580 by June 2024, while cumulative CHCs increased from 397 by 2019-20 to 685 by 2023 and 832 by 2025 [45,46].

This creates a distinction between physical scale and functional scale.

Fragmented physical holdings do not necessarily imply fragmented economic organization.

These institutional stocks are observable manifestations of functional-scale capacity. They do not establish the effectiveness of individual organizations, but they demonstrate that mechanisms for

collective organization and shared technology access are present and expanding. Relative to the 2015-16 benchmark of 16.413 million operational holdings, FPO density rose from about 13.5 to 35.3 per million holdings between 2021 and 2024, while CHC density reached about 50.7 per million holdings at the latest reporting point [31,45,46].

The transformation pathway may therefore be expressed as:

Fragmented holdings + institutional coordination → functional scale → technology access and aggregation → value-chain participation → localized value creation.

This interpretation does not treat land fragmentation as an absolute barrier to agricultural modernization. Bihar's high cropping intensity and large production volumes demonstrate that smallholder agriculture can generate considerable productive capacity. Fragmentation becomes more restrictive when technologies, infrastructure or market transactions require substantial economic scale.

The evidence therefore provides empirical support for the operationalization of functional scale as institutional capacity, while maintaining a clear distinction between capacity and impact. Fragmentation can create scale-related constraints, and collective and shared-service institutions provide observable mechanisms for addressing them; the data do not establish the magnitude of their causal effect on value creation.

4.5. Structural Diversification of the Bihar Economy

Changes in the sectoral composition of GSVA indicate gradual economic diversification. Agriculture's share declined from 23.11% in 2023-24 to 22.37% in 2024-25, while industry increased from 23.06% to 23.57% and services from 53.84% to 54.07% [26,33].

Table 4.3. Sectoral composition of GSVA in Bihar

Sector	2023-24 (%)	2024-25 (%)	Change (percentage points)
Agriculture	23.11	22.37	-0.74
Industry	23.06	23.57	+0.51
Services	53.84	54.07	+0.23

Source: Directorate of Economics and Statistics, Government of Bihar [26,33].

A declining agricultural share should not be interpreted as agricultural decline. Bihar's substantial production and increasing cropping intensity indicate continuing agricultural dynamism. The observed pattern is more appropriately interpreted as structural diversification, in which agriculture remains important while industry and services gain relative significance. The development objective is therefore not simply movement away from agriculture, but the strengthening of activities within and around agriculture, including processing, machinery services, storage, logistics, transportation, marketing, finance and digital services.

4.6. Agriculture-Industry-Services Linkages

Agricultural modernization can contribute to structural transformation through both backward and forward linkages.

Backward linkages include agricultural inputs, machinery, irrigation, finance, insurance and technical services. Forward linkages include aggregation, storage, transportation, processing, packaging, quality certification and marketing.

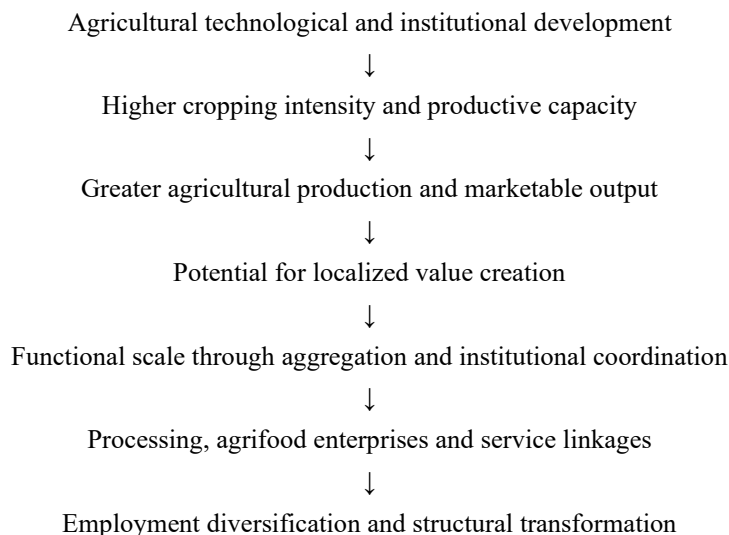
Bihar's large agricultural production base and observable downstream processing activity provide evidence of an emerging agriculture-industry interface. However, available aggregate data do not permit precise measurement of the proportion of output processed within Bihar or the value retained at successive stages of agricultural value chains. Accordingly, the evidence demonstrates realized processing activity and institutional capacity, but not a statewide value-retention rate.

Accordingly, the evidence should not be interpreted as demonstrating that Bihar already captures all potential downstream value. Rather, it demonstrates that the state possesses both the productive foundation and some observable institutional and industrial capacity required for a stronger agriculture-industry-services system.

The critical policy challenge is therefore to strengthen the institutional and infrastructural mechanisms through which this potential can be converted into localized economic activity.

4.7. Empirically Observed Transformation Pathway

The empirical evidence can be synthesized into the following pathway:



The pathway is conditional rather than automatic. Bihar has developed substantial productive capacity, but the transition from production to localized value creation depends upon the ability to organize dispersed agricultural output at economically viable scale.

Functional scale is therefore the central intervening mechanism linking agricultural modernization with broader structural transformation.

4.8. Assessment of the Analytical Propositions

Proposition 1: Agricultural technological development contributes to productive capacity and marketable output.

Assessment: Broadly supported. High cropping intensity and substantial agricultural production indicate considerable productive capacity [2-9,24,31,32].

Proposition 2: Higher productive capacity creates the potential, but does not automatically ensure, localized value addition.

Assessment: Supported as a bounded empirical proposition. Bihar possesses a substantial production base and measurable downstream processing activity, but the available statistics cannot establish the share of agricultural value actually retained within Bihar.

Proposition 3: Fragmented holdings can constrain the conversion of productive capacity into value creation where substantial economic scale is required.

Assessment: Structurally supported. Small holdings may be compatible with production growth but can create constraints for capital-intensive infrastructure, aggregation and large-scale market participation [21,35].

Proposition 4: Functional scale created through collective and institutional arrangements can reduce the disadvantages associated with fragmented holdings.

Assessment: Supported as an operational and institutional proposition. FPO and CHC indicators demonstrate the presence and expansion of mechanisms capable of creating organizational or operational scale, while the short proxy series does not permit causal estimation of their effect [36-40,45,46].

Proposition 5: Localized value addition can strengthen agrifood linkages and contribute to structural transformation.

Assessment: Supported as a transformation pathway rather than as a quantified causal relationship. Bihar's downstream processing activity and gradual diversification towards industry and services are consistent with the pathway, but the state-level data do not identify the amount of value retained locally.

4.9. Summary of Empirical Results

The empirical findings establish four central conclusions. First, Bihar possesses substantial agricultural productive capacity, reflected in high cropping intensity and large production volumes. Second, measurable institutional proxies show an expansion of collective-organization and shared-mechanization capacity, providing observable content to the concept of functional scale. Third, downstream processing is demonstrably present in food processing, sugar and ethanol, and this production base provides significant potential for localized value creation through processing, storage, logistics and related agrifood activities; however, the available evidence does not permit calculation of the statewide proportion of agricultural value retained locally. Fourth, Bihar is experiencing gradual structural diversification, with industry and services increasing their relative contribution to GSVA.

Land fragmentation should therefore not be interpreted as an absolute obstacle to agricultural modernization. Its principal importance arises where downstream activities require economic scale. The critical transformation challenge lies in converting agricultural productive gains into locally retained value. The central policy implication is consequently that Bihar's next stage of agricultural transformation depends not only on increasing technology adoption and production, but also on strengthening the institutional and infrastructural capacity through which dispersed productive resources can be organized at economically viable scale and connected with downstream value-adding activities. The revised evidence supports this as a plausible and partially observable transformation pathway, not as a fully identified causal mechanism, and provides the empirical basis for the policy implications and institutional strategies developed in Section 5.

5. DISCUSSION AND POLICY IMPLICATIONS

5.1. From Agricultural Modernization to Technology-Enabled Value Creation

The empirical findings indicate that Bihar's agricultural transformation should not be assessed solely through agricultural output, productivity or cropping intensity. These indicators demonstrate substantial productive capacity, while the new proxy evidence demonstrates expanding institutional capacity for collective organization and shared technology access. Downstream processing indicators further show that value-adding activity is occurring within Bihar, although the amount of total agricultural value retained locally remains unmeasured.

The central distinction emerging from the analysis is therefore between productive capacity and transformative capacity. Bihar possesses a substantial agricultural production base and is simultaneously experiencing gradual economic diversification. The critical development challenge is to strengthen the institutional and economic mechanisms connecting agricultural production with processing, logistics, agrifood enterprises and higher-value services.

Accordingly, the next stage of agricultural modernization should move beyond increasing production alone towards:

Technology → productive capacity → marketable output → functional scale → localized value creation → agrifood linkages → structural transformation.

This interpretation shifts attention from technology adoption as an isolated farm-level objective towards the institutional conditions required to convert technological gains into wider economic transformation.

5.2. Functional Scale as the Central Institutional Policy Principle

The principal contribution of this study is the concept of functional scale. The fundamental policy question is not simply whether individual farmers own sufficiently large holdings, but whether production, technology, infrastructure and market transactions can be organized at an economically viable scale.

Small ownership need not imply small-scale economic organization. Farmers can retain individual ownership while participating collectively in activities requiring larger economic scale.

Functional scale can be created through:

1. Farmer Producer Organizations and producer enterprises;

2. collective procurement and marketing;
3. coordinated or synchronized production;
4. custom-hiring and shared machinery services;
5. aggregation and collection systems;
6. common storage and processing facilities;
7. voluntary land-leasing arrangements; and
8. coordinated logistics and value-chain institutions.

These mechanisms can enable smallholders to access technologies, infrastructure and markets that would be difficult to obtain individually. The appropriate policy objective is therefore not necessarily compulsory land consolidation, but the creation of economically viable organizational and operational scale.

5.3. Land Fragmentation as an Organizational Challenge

Land fragmentation remains an important structural constraint, but its effects should not be interpreted uniformly. Bihar's substantial agricultural production demonstrates that smallholders can adopt technologies and achieve significant productive intensity.

Constraints become more important where activities require substantial fixed investment, specialized infrastructure, coordinated production, aggregation or large-volume transactions. Fragmentation therefore affects transformation primarily by limiting the conversion of productive capacity into downstream value creation.

The policy response should consequently be differentiated. Individual farmer support may be appropriate where technologies can operate efficiently at small scale. Where economic activities require larger scale, collective and institutional mechanisms become essential.

The central transition is therefore:

Fragmented physical holdings → coordinated economic organization → functional scale.

This reframes land fragmentation from being solely a physical constraint into an institutional and organizational challenge.

5.4. Strengthening Collective Institutions and Producer Organizations

Farmer Producer Organizations, cooperatives and other producer institutions can play an important role in creating functional scale. Their potential contribution extends beyond collective membership to the organization of economic activities requiring aggregation and coordination.

Priority functions include:

1. collective input procurement;
2. technology dissemination and advisory services;
3. machinery and custom-hiring services;
4. aggregation and quality standardization;
5. storage and primary processing;
6. collective marketing and market intelligence; and
7. commercial relationships with processors and organized buyers.

However, the effectiveness of such institutions depends upon professional management, financial capacity, transparent governance and sustainable commercial operations. Policy should therefore emphasize the economic viability and business capability of collective institutions rather than simply increasing their number.

5.5. From Technology Ownership to Technology Access

Fragmented smallholders need not individually own all capital-intensive technologies. An important policy transition is therefore from technology ownership towards technology access.

Custom-hiring centres, machinery pools, FPO-managed services and private agricultural service providers can enable farmers to obtain timely access to mechanization and other technologies at economically viable costs.

This approach can also extend to irrigation, drying, grading, storage, transportation and selected digital and precision-agriculture services. The policy objective should be to maximize effective access to appropriate technologies rather than individual ownership of capital-intensive assets.

5.6. Building Commodity-Based Agrifood Value-Creation Systems

Bihar's large production base provides opportunities for strengthening commodity-specific value chains. Policy should therefore connect agricultural production more systematically with downstream processing and services.

Particular attention can be directed towards commodities with substantial production volumes and identifiable value-chain opportunities, including rice, wheat, maize, sugarcane, horticultural products, livestock and fisheries.

The strategic objective should be:

Production → aggregation → quality improvement → storage → processing → branding and marketing → localized value retention.

Processing infrastructure should be linked with reliable raw-material supply, aggregation systems, logistics and markets. Isolated investments in processing facilities without these complementary arrangements are unlikely to generate sustained transformation.

5.7. Infrastructure, Markets and Institutional Coordination

Functional scale alone cannot generate value creation. Its effectiveness depends upon complementary infrastructure and institutions.

Priority investments include:

1. storage and warehousing;
2. drying and post-harvest facilities;
3. cold-chain infrastructure where economically justified;
4. transportation and logistics;
5. quality testing and certification;
6. market information and digital platforms; and
7. improved links between producers, processors and consumers.

The central policy requirement is coordination. Technology, aggregation, infrastructure and processing should be developed as interconnected components of an integrated agrifood system rather than as isolated interventions.

5.8. An Integrated Policy Framework

The findings suggest five mutually reinforcing policy pillars:

Pillar 1: Strengthen productive capacity

Promote appropriate technologies, irrigation, diversification, climate resilience and productivity improvement.

Pillar 2: Create functional scale

Support aggregation, collective institutions, coordinated production, shared services and voluntary operational consolidation.

Pillar 3: Expand technology access

Develop custom-hiring, machinery services and other access-based technological systems.

Pillar 4: Promote localized value creation

Strengthen storage, processing, logistics, quality improvement, branding and agrifood enterprises.

Pillar 5: Deepen agriculture-industry-services linkages

Connect agricultural production with manufacturing, business services, transportation, finance and digital activities.

These pillars are complementary. Technology without aggregation may have limited downstream effects; aggregation without infrastructure may not generate value addition; and processing without reliable production and market coordination may remain underutilized.

The broader policy principle is therefore clear:

The objective should not be to make every farm physically large, but to enable farmers to participate in economic systems operating efficiently at the scale required by technology, infrastructure and markets.

5.9. Limitations and Future Research

The findings should be interpreted within the limitations of aggregate state-level evidence. The analysis identifies structural patterns and associations consistent with the proposed transformation pathway but does not establish definitive causal effects at the farm, enterprise or value-chain level.

Future research should develop linked farm-, district-, enterprise- and value-chain-level datasets incorporating land fragmentation, technology adoption, mechanization access, participation in collective institutions, processing capacity, value realization and employment outcomes.

Panel and quasi-experimental approaches could provide stronger evidence concerning the effects of FPO participation, custom-hiring services, land-leasing arrangements, collective production and post-harvest infrastructure.

Nevertheless, the available evidence supports a more precise conclusion than the original version: Bihar has substantial productive capacity; institutional proxies of functional-scale capacity have expanded; downstream processing activity is observable; and the economy is diversifying. The remaining empirical gap is the direct measurement of how these institutional mechanisms alter the distribution and retention of agricultural value.

5.10. Summary of Discussion and Policy Implications

Bihar has demonstrated substantial agricultural productive capacity. The next stage of transformation requires mechanisms capable of converting productive capacity into greater downstream activity and, where possible, greater locally retained value. Measuring that retention should become a priority for future Bihar value-chain statistics.

The principal structural challenge is therefore not simply the size of individual farms. It is the creation of the functional scale required for technology, infrastructure and value-chain activities to operate efficiently.

Bihar's agricultural modernization should consequently move beyond isolated technology adoption towards technology-enabled value creation organized through collective institutions, functional scale and integrated agrifood systems.

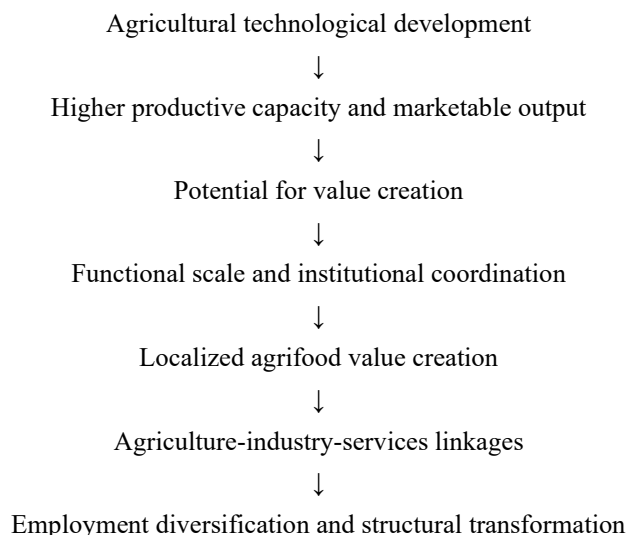
6. CONCLUSION

This study examined the relationship among agricultural technological development, localized value creation and structural transformation in Bihar within the context of a predominantly smallholder agricultural economy characterized by fragmented operational holdings.

The central finding is that productive agricultural modernization does not automatically establish downstream value creation or structural transformation. Bihar has developed substantial agricultural productive capacity, reflected in intensive land use and large volumes of marketable agricultural output. These achievements provide an important foundation for downstream agrifood development, while the revised evidence shows that institutional and processing capacities are also present.

The analysis also indicates that Bihar is undergoing gradual structural diversification rather than agricultural decline. Agriculture remains economically important while industry and services are increasing their relative contribution to the state economy. Structural transformation should therefore not be interpreted simply as movement away from agriculture, but as the development of stronger and more productive activities within and around the agrifood system.

The principal transmission challenge lies in converting agricultural productive gains into downstream value-adding activity through aggregation, storage, processing, logistics, marketing and related services. The revised evidence demonstrates observable institutional capacity through FPOs and CHCs and observable downstream activity through food processing, sugar and ethanol. It does not, however, quantify the share of agricultural value retained locally.



The principal theoretical contribution of the study is the identification and empirical operationalization of functional scale as an institutional capacity in this process. Small and fragmented holdings need not prevent technological progress, as Bihar's productive capacity demonstrates. The more significant constraint arises where technologies, infrastructure and downstream economic activities require larger operational scale, substantial investment, aggregation or coordinated transactions.

The appropriate response is therefore not necessarily compulsory physical consolidation of land ownership. Organizational and operational scale can instead be created through Farmer Producer Organizations, producer enterprises, collective action, coordinated production, custom-hiring services, shared infrastructure, aggregation systems, voluntary land-leasing arrangements and integrated value-chain institutions.

The broader policy implication is that small ownership need not imply small-scale economic organization. Bihar can pursue an inclusive transformation strategy in which smallholders retain ownership while participating in economic systems operating at scales appropriate for modern technologies, infrastructure and markets.

The study therefore concludes that Bihar's next stage of agricultural transformation should move beyond the objective of increasing technology adoption and production alone. The strategic priority is to strengthen the institutional, organizational and infrastructural conditions through which technological and productive gains can be organized at economically viable scale and connected with downstream value-adding activities, while developing better statistics to measure actual local value retention.

The central proposition is consequently:

Technology becomes more likely to be structurally transformative when institutions enable productive gains to achieve functional scale and connect dispersed production with downstream value-adding activities. The available evidence supports this pathway, but does not yet quantify its causal effect or the proportion of value retained locally.

Although the evidence is based primarily on aggregate state-level patterns and does not establish definitive causal effects, the revised proxy and downstream-indicator analysis provide measurable empirical content for the functional-scale concept while clearly delimiting what can and cannot be inferred about localized value retention.

More broadly, the concept of functional scale may have relevance beyond Bihar. In densely populated agrarian economies where smallholder ownership is persistent, inclusive structural transformation need not depend exclusively on creating larger farms. It can also emerge through

institutions capable of organizing fragmented resources into economically viable systems of technology access, production, aggregation and value creation.

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Data Availability Statement: The study is based entirely on secondary data obtained from publicly available sources. The datasets supporting the findings were compiled from official publications and databases of the Government of India, the Government of Bihar and other publicly accessible institutional sources cited in the References. No primary data were generated for this study. The underlying data are available from the respective source organizations and publications, and sufficient bibliographic information has been provided to facilitate verification and replication.

Author Contributions: The author was responsible for the conceptualization, methodology, investigation, data curation, formal analysis, interpretation, visualization, writing of the original draft, review and editing, validation and final preparation of the manuscript.

Ethical Statement: This study did not involve human participants, human data, human tissue or animals. Accordingly, formal ethical approval was not required.

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