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Bihar's Fixed Capital Accumulation, 1980–2025: Structural Transformation, Capital-Deepening Conditions and Conditional Pathways to 2050

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ABSTRACT: This study examines Bihar's long-run productive fixed-capital trajectory from 1980–81 to 2024–25 and develops conditional capital-accumulation pathways to 2050. The analysis extends an earlier state-level Net Fixed Capital Stock (NFCS) series estimated at 2011–12 prices using the Perpetual Inventory Method (PIM). Rather than treating capital accumulation as synonymous with productive capacity, the study distinguishes the measured stock of fixed assets from capital services, utilization, asset composition and complementary capabilities. The historical evidence identifies a major change in the aggregate accumulation regime around 2005–06, followed by a substantial expansion of tertiary capital. An author-updated 2024–25 benchmark indicates continued accumulation but a lower endpoint growth rate than that observed during the post-2005 period. Three conditional pathways—4.5%, 6.0% and 8.0% annual real NFCS growth—illustrate the implications of alternative accumulation regimes through 2050. These pathways are scenario calculations rather than probabilistic forecasts. The paper contributes by integrating long-run capital-stock measurement with structural-transformation analysis and by identifying the complementary conditions—productive-sector investment, connectivity, energy, digital capability, human capital, utilization and resilience—under which a larger asset base can translate into greater productive capital services. The results indicate that Bihar's long-run challenge is not simply to increase the quantity of fixed capital, but to improve its composition, utilization, connectivity and productivity. The study concludes with a reproducibility framework and a set of measurable indicators for evaluating capital deepening over the 2025–2050 horizon.

Keywords: Net Fixed Capital Stock, Capital accumulation, Capital deepening, Perpetual Inventory Method, Structural transformation, Capital services, Productivity, Resilience, Bihar, 2050 scenarios.

1. INTRODUCTION

Capital accumulation is a fundamental mechanism through which an economy expands productive capacity, but the developmental effect of investment depends on what is accumulated, where it is allocated, how intensively it is used and what complementary capabilities accompany it. Fixed assets—including machinery, buildings, transport equipment, irrigation systems, electricity networks, communication infrastructure and urban systems—generate productive services over several periods. Modern productivity analysis therefore distinguishes between the net wealth value of capital and the flow of capital services used in production [1–3].

The central measurement problem is that capital accumulation and capital deepening are related but non-identical processes. An increase in the monetary or volume stock of fixed assets does not necessarily imply an equivalent increase in productive capacity. The

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productive contribution of capital depends on asset composition, age and efficiency, depreciation, utilization, complementary labor and technology, and the allocation of assets across activities. OECD capital-measurement methodology therefore distinguishes wealth stocks from the productive services generated by capital assets, while contemporary productivity databases increasingly incorporate asset-specific capital composition and capital-service measures [1–3].

For Bihar, this distinction is particularly important. The earlier study by Sinha and Sinha established a state-level NFCS series for 1980–81 to 2016–17 and identified a major aggregate turning point in 2005–06. Aggregate NFCS increased from ₹1,06,600.57 crore in 1980–81 to ₹3,41,783.89 crore in 2016–17, while tertiary capital became the dominant component of the stock [4]. The present article retains those empirical foundations but asks a broader question: whether the quantity, composition and productivity orientation of accumulated capital are sufficient to support sustained structural transformation through 2050. Bihar provides a particularly useful setting for examining this distinction because the state has experienced substantial changes in sectoral output composition, infrastructure provision and capital accumulation while continuing to exhibit a large dependence on agriculture and substantial productivity differences across sectors. The analytical question is consequently not whether Bihar has accumulated capital, but whether the changing composition of its capital stock is capable of supporting sustained productivity growth and structural transformation.

The unresolved issue is therefore one of measurement and interpretation rather than simply the volume of investment. A rising NFCS establishes that the accumulated stock of fixed assets has increased, but it does not by itself establish that the economy has experienced equivalent capital deepening. The latter depends on the quantity, composition, age, utilization and complementary use of capital. This distinction is particularly important for Bihar because the available long-run evidence permits reconstruction of the capital stock but does not yet provide a sufficiently detailed state-level capital-services series. The present study therefore treats NFCS as the empirical foundation for analyzing capital accumulation and uses structural-transformation evidence to identify the conditions under which that accumulation could translate into capital deepening.

The contemporary relevance of this question has increased because Indian structural transformation has remained incomplete. Recent evidence finds persistent interstate heterogeneity, limited convergence of sectoral productivity and, in many states, movement of labour from agriculture toward services without a conventional manufacturing transition [5, 6]. IMF evidence similarly shows that agriculture continues to employ a large share of Indian workers despite its much smaller contribution to output, while productivity catch-up has been uneven across sectors [7]. The World Bank's recent assessment also emphasises that relatively slow inter-sectoral and inter-regional labour reallocation has limited productivity gains compared with successful structural-transforming economies [8].

The contribution is fourfold. First, the paper provides a long-run state-level NFCS trajectory spanning the pre-reform period, the post-2005 acceleration and the 2017–2025 update. Second, it places capital accumulation within a capital-services framework, clarifying why a larger stock is a necessary but insufficient condition for capital deepening. Third, it connects the stock trajectory to structural transformation through sectoral complementarity, market access, human capability and resilience rather than assuming a linear agriculture–manufacturing–services sequence. Fourth, it provides a transparent scenario and reproducibility architecture, including formal breakpoint testing, a 3–9% continuous sensitivity grid, deflator stress testing, an explicit PIM-consistent investment identity and a measurable monitoring framework. The study therefore makes a deliberately bounded contribution: it establishes an empirically anchored capital-stock base and a theoretically coherent bridge toward future state-level capital-services and productivity research, without claiming to estimate capital-service growth or causal productivity effects.

2. RESEARCH QUESTIONS AND ANALYTICAL PROPOSITION

- How did Bihar's aggregate and sectoral capital stock evolve across distinct economic-development regimes from 1980–81 to 2024–25?
- How should the post-2005–06 acceleration and the subsequent 2017–2025 moderation be interpreted in relation to structural transformation?
- What capital-stock trajectories would result from alternative sustained accumulation regimes through 2050?
- Under what conditions does a larger capital stock become capital deepening rather than simply a larger measured asset base?

- Which combinations of physical, digital, human and resilience capital are most relevant to Bihar's structural transformation?
- How sensitive are the estimated capital-stock levels and long-run conclusions to alternative assumptions concerning the initial capital stock, depreciation rates, service lives and real-investment deflators?

The first two questions are addressed through the historical NFCS trajectory and periodization in Sections 4–7; the third through the conditional scenario analysis in Section 9; the fourth and fifth through the capital-composition and structural-transformation analysis in Sections 8 and 11; and the sixth through the uncertainty and sensitivity framework in Section 13 and the supplementary material.

The study advances a conditional analytical proposition rather than a causal hypothesis. Capital accumulation creates the potential for capital deepening, but the translation of that potential into higher productive capacity depends on asset composition, utilization, technology, labor quality, infrastructure connectivity and inter-sectoral complementarities. Accordingly, a larger NFCS should be interpreted as an increase in the stock of potentially productive assets, while evidence of capital deepening requires additional information on capital services, capital per worker, utilization or productivity. The empirical analysis therefore separates what can be established from the NFCS data from what remains a hypothesis for subsequent productivity research.

3. LITERATURE REVIEW

3.1. Capital-Stock Measurement, PIM and Capital Services

The PIM remains the principal practical approach for estimating capital stocks where direct asset inventories are incomplete. It recursively carries forward surviving assets, adds new investment and subtracts consumption of fixed capital. Nehru and Dhareshwar's cross-country database established an influential physical-capital-stock application [9]. OECD capital-measurement guidance subsequently formalised the distinction between wealth stocks and productive capital services, with asset-specific depreciation and efficiency profiles central to the latter [1, 2].

The India KLEMS programme is especially relevant. Its methodology constructs capital stocks and capital services for 27 industries from 1980–81 onward, using asset-specific approaches and capital-composition effects. The 2024 KLEMS documentation explicitly notes that capital services account for differences in marginal productivity and asset efficiency that conventional aggregate stock measures do not capture [3]. This distinction provides a methodological bridge for the present paper: NFCS is appropriate for long-run stock accumulation, but a future Bihar productivity study should progressively move toward capital-service measurement.

3.2. Capital Deepening and Productivity

Capital deepening is conventionally associated with an increase in capital input relative to labor input, whereas the present study does not estimate capital per worker or capital services. Accordingly, the term "capital deepening" is used here as an analytical framework rather than as an estimated empirical outcome.

Growth accounting separates factor accumulation from productivity. Capital deepening—more capital input per worker—can increase labour productivity, while total factor productivity reflects efficiency and technological change not captured by measured factor quantities. India KLEMS evidence demonstrates that capital composition and capital services matter for understanding output and productivity growth [3, 10]. RBI evidence also indicates that ICT capital has become increasingly relevant to productivity and that capital utilisation can affect measured TFP [11]. These findings caution against interpreting a rising NFCS as equivalent to a proportional increase in productive capacity.

Misallocation provides a second qualification. Hsieh and Klenow's India evidence shows that inefficient allocation of capital and labour across firms can materially reduce manufacturing productivity [12]. For Bihar, the implication is that aggregate investment targets should be accompanied by policies that improve access to finance, technology, power, logistics and productive scale for firms and farms.

3.3. Structural Transformation and Labour Reallocation

Structural transformation traditionally involves the movement of labour and resources from low-productivity agriculture toward manufacturing and services, together with within-sector productivity growth [13,14]. India has followed a distinctive services-oriented pathway. IMF research documents a large decline in agriculture's output share while agriculture remains a major employer, with construction and trade absorbing many workers but showing relatively limited technological catch-up [7].

Recent state-level research reinforces the heterogeneity of this process. Thasni, Gangopadhyay and Mondal find that many Indian states bypassed a conventional manufacturing stage and moved labour directly toward modern services, while sectoral productivity convergence remained weak [5]. Their 2025 decomposition further finds that reallocation contributed modestly to aggregate productivity growth in most states, with within-sector productivity growth playing the larger role [6]. This evidence is directly relevant to Bihar: capital deepening must raise productivity within agriculture, manufacturing and services as well as facilitate labour reallocation.

3.4. Manufacturing, Services and Productive Linkages

Services have been a major driver of Indian growth since the 1990s. Goldar, Das and Dutta find that market services expanded rapidly and that manufacturing TFP growth had a significant positive effect on productivity growth in both market and non-market services [15]. Recent research also argues that manufacturing expansion can support advanced service employment through intermediate-goods specialisation and demand for business services [16]. Thus, the choice between manufacturing and services is analytically misleading. Bihar requires complementary production networks in which manufacturing, agro-processing, logistics, finance and modern services raise one another's productivity.

3.5. Infrastructure, Connectivity and Market Access

Infrastructure can affect productivity through lower transaction costs, larger effective markets and stronger specialisation. Classic public-capital research links infrastructure to productivity [17], while market-access approaches emphasise the role of transport connectivity in raising the value of productive activity [18]. For Bihar, roads, railways, inland waterways, warehouses, cold chains and digital logistics should therefore be considered complementary assets rather than independent projects.

3.6. Digital and Intangible Capital

Digital infrastructure increasingly acts as general-purpose capital. RBI evidence reports a rising contribution of ICT capital services to Indian output and labour-productivity growth [11]. For a state with dispersed production and large service-sector potential, digital capital can reduce information costs, improve financial inclusion, enable e-commerce and support formalisation. However, digital infrastructure generates productivity only when complemented by skills, reliable power, enterprise capability and access to markets.

3.7. Climate Resilience and Green Capital

Green and resilience capital are considered here as prospective components of the broader capital-deepening framework rather than separately estimated components of Bihar's historical NFCS.

Climate risks change the economics of long-lived infrastructure. Flood protection, drainage, water management, resilient roads, decentralised energy, clean production and circular systems should increasingly be viewed as productive capital because they protect the service flow of existing assets and reduce future disruption. This broadens the capital-deepening concept from conventional physical capital toward productive and resilience-adjusted capital.

3.8. Research Gap

Three gaps remain. First, state-level Indian structural-transformation studies have generally concentrated on output, employment and labor productivity, whereas long-run state-level physical-capital trajectories have received comparatively less systematic integration with structural-transformation analysis. Second, capital-stock studies frequently report accumulated assets without explicitly distinguishing stock from capital services. Third, long-horizon capital scenarios are rarely connected to an explicit reproducibility framework that exposes initial-stock, depreciation, service-life and deflator assumptions. Fourth, there is a limited empirical bridge between long-run state-level capital-stock measurement and forward-looking scenario analysis that explicitly separates mechanical stock accumulation from the institutional and productivity conditions required for capital deepening. The present study addresses these gaps for Bihar by combining a historical NFCS series, regime-based periodization, a capital-deepening interpretation, sensitivity analysis and conditional 2050 pathways. The contribution is therefore integrative rather than a claim to have estimated a complete causal productivity model.

3.9. Theoretical Synthesis: From Accumulation to Productive Capital Deepening

The preceding literature can be synthesized into four propositions that organize the empirical interpretation. Proposition 1—stock–service wedge: an increase in

NFCS raises the potential capital input, but the resulting service flow depends on asset composition, age, efficiency and utilization. Proposition 2—complementarity: infrastructure, digital systems and tertiary assets are more productive when combined with sector-specific capital, skills, energy and market access; hence the productivity effect of one asset class can depend on the availability of complementary assets. Proposition 3—structural transformation: capital accumulation can support structural change through both within-sector productivity gains and between-sector reallocation, but the aggregate effect depends on whether labour and capital move toward higher-productivity activities. Proposition 4—resilience-adjusted accumulation: in a flood-exposed economy, part of gross investment is economically required to preserve the service flow of existing assets; therefore, higher gross formation need not translate one-for-one into net productive stock. These propositions are not econometric hypotheses estimated in the present paper. They define the causal channels that a future Bihar capital-services database should test.

3.10. From Capital-Stock Measurement to Capital-Service Measurement

The methodological literature implies a hierarchy of capital measurement. At the first level, gross and net capital stocks describe the accumulated asset base. At the second level, productive capital stocks account for the loss of efficiency associated with ageing assets. At the third level, capital services measure the flow of productive services entering the production process. The distinction matters because two economies with identical net capital stocks can generate different productive services when their asset composition, age distribution, utilization and efficiency differ [1–3]. India KLEMS provides an important national benchmark by constructing capital-stock, capital-composition and capital-service measures within a consistent productivity framework [3,10].

The present study deliberately stops at the NFCS level because a sufficiently detailed Bihar asset-by-industry capital-services database is not yet available within the study. Consequently, the paper should not interpret changes in NFCS as direct estimates of changes in capital input. Instead, NFCS is treated as the measurable long-run stock from which a future Bihar capital-services series can be developed.

4. ANALYTICAL PERIODIZATION OF BIHAR'S CAPITAL TRAJECTORY, 1980–2050

The periodization combines historical interpretation with formal stability testing. The 1980–2005 and 2005–2017 windows retain the substantive interpretation of the earlier study, while the 2017–2025 boundary is evaluated directly on the complete 1980–81 to 2024–25 benchmark series. A log-linear trend in ln(NFCS) is estimated and Chow tests are applied at 2005–06 and 2017–18. The resulting F-statistics—300.44 ($p<0.001$) and 5.00 ($p=0.011$), respectively—reject parameter stability at both dates under the stated specification. The 2005–06 result strongly corroborates the inherited turning point. The 2017–18 result provides evidence of a second change in the trend relationship, but it should not be interpreted as proof of a causal policy break because the post-2017 observations are an author-derived benchmark and the test identifies statistical instability rather than its cause. The periodization is therefore used as a regime-based empirical structure, not as a causal chronology.

Table X: Theoretical propositions linking capital accumulation to productive capital deepening

Proposition	Mechanism	Observable indicator for future testing	Implication for this study
Stock–service wedge	Composition, age, efficiency and utilization mediate the conversion of stock into services	Capital services; asset age; utilization	NFCS is interpreted as potential capital input, not services
Complementarity	Network and sectoral assets raise the productivity of complementary factors	Cross-sector capital ratios; connectivity; energy reliability; skills	Tertiary capital is assessed through complementarities, not sectoral dominance
Structural transformation	Within-sector productivity and inter-sector reallocation jointly determine aggregate gains	Sectoral LP, employment shares, reallocation effects	Capital accumulation is linked to transformation without assuming a linear sequence
Resilience-adjusted accumulation	Climate damage and replacement needs reduce effective service flows and absorb gross investment	Disruption days; replacement expenditure; resilience-adjusted service flow	Scenario pathways include maintenance and resilience conditions

Phase	Period	Basis for boundary	Empirical status
I	1980–1991	Pre-reform period	Analytical
II	1991–2001	Post-reform transition	Analytical
III	2001–2005/06	Pre-break acceleration	Analytical + historical evidence
IV	2005/06–2011	Post-break acceleration	Empirically identified break
V	2011–2017	Consolidation	Analytical
VI	2017–2025	Updated benchmark period	Data-defined
VII–IX	2025–2050	Investment/planning horizons	Scenario-defined

5. DATA AND METHODOLOGY

5.1. Historical PIM

The historical series follows the author's published methodology [4]. The initial stock is represented as $K_0 = I_0(1+g)/(g+\delta)$, where I_0 is initial-period investment, g is the average subsequent investment-growth rate and δ is the depreciation rate. The recursive PIM identity is $K_t = (1-\delta)K_{t-1} + I_t$. The series is expressed at 2011–12 prices and grouped into primary, secondary, Tertiary-I and Tertiary-II components.

For a constant depreciation formulation, the recursive stock equation is:

$$K^N_t = (1-\delta)\, K^N_{t-1} + I^R_t$$

Where K^N_t is net fixed capital stock, (δ) is the assumed annual depreciation rate and (I^R_t) is real gross fixed capital formation. Where asset-specific rates are used, the equation is applied separately by asset or sector and subsequently aggregated.

The PIM produces an estimated stock series; it does not directly measure the flow of productive capital services generated by that stock.

The initial stock is particularly important because the effect of an initial-stock error can persist for many subsequent years. The initial-stock formulation adopted in the earlier study is therefore retained for historical comparability, while alternative initial-stock assumptions are proposed as a sensitivity test. Because the initial-stock estimate affects the level of the entire subsequent series, the analysis treats the initial stock as a principal source of parameter uncertainty rather than as an innocuous starting value. The historical specification is retained for comparability with the earlier published series, while alternative initial-stock assumptions are identified as a sensitivity dimension.

5.1.1. Data Provenance and Classification

The empirical database should distinguish between source observations and author-derived quantities. Investment/GFCF observations and price indices obtained from official statistical sources are treated as source data; conversion to constant prices, aggregation across sectors, depreciation, initial-stock construction and recursive stock estimation are treated as derived calculations. The supplementary workbook identifies the source, transformation and parameter used for each series. This distinction is important because the resulting NFCS is an analytical estimate rather than a directly observed statistical quantity.

Sectoral stocks are classified into Primary, Secondary, Tertiary-I and Tertiary-II categories consistently with the historical study. Any changes in classification or source methodology between the historical and updated periods should be documented explicitly.

5.2. Updated 2024–25 Benchmark

Indicator	Value	Status
NFCS, 2016–17	₹3,41,783.89 crore	Original published PIM series; 2011–12 prices
NFCS, 2024–25	₹5,02,565.85 crore	Author-updated PIM benchmark; 2011–12 prices
Real GSDP, 2024–25	₹5,31,372 crore	Official benchmark cited in source manuscript
GFCF, 2024–25	₹34,905 crore	Official state estimate cited in source manuscript
NFCS/GSDP	0.946	Descriptive stock-output ratio

The 2024–25 value of ₹5,02,565.85 crore should be interpreted as an author-updated PIM benchmark, not as an official published NFCS statistic. The benchmark extends the historical framework using the available post-2016–17 investment information and the stated PIM assumptions. Because the complete annual post-2016–17 calculation schedule is not reproduced in the main text, the benchmark is not independently reproducible from the article alone. To address this limitation, the submission should provide Table **S1** containing annual investment/GFCF inputs, Table **S2** containing depreciation, service-life and initial-stock assumptions, and Table **S3** containing the resulting annual sectoral and aggregate NFCS series. The benchmark should therefore be regarded as an empirical extension subject to the documented assumptions rather than as a new official national-accounts estimate.

The 2016–17 to 2024–25 endpoint CAGR is 4.94%. The annual benchmark growth rates are 4.15%, 4.68%, 4.58%, 3.38%, 5.33%, 5.84%, 5.95% and 5.61% from 2017–18 through 2024–25. These values show continued accumulation with some year-to-year variation rather than a smooth linear moderation. They are therefore used descriptively, while the endpoint CAGR provides the most compact measure for comparison with the earlier high-accumulation regime.

5.3. Scenario Framework

The scenario exercise is deliberately parsimonious. Its purpose is not to forecast Bihar's capital stock but to quantify the compounding implications of alternative sustained accumulation regimes. The mechanical stock equation is K_t = K_2024–25(1+g)^n. To preserve PIM accounting consistency, the corresponding gross real investment requirement is I_t^R = (g+δ)K_{t−1}. With the benchmark aggregate depreciation assumption δ=5%, the 4.5%, 6.0% and 8.0% net-stock pathways imply gross real investment requirements equal to 9.5%, 11.0% and 13.0% of the preceding net stock, respectively. These are accounting requirements for sustaining the scenario paths, not forecasts of actual GFCF and not policy targets. A statistical forecast would require a dynamic model of investment, depreciation, output, finance, demography, technology and climate shocks and is outside the scope of the present study.

The scenario equation is: $K_t = K_{2024–25}\,(1+g)^n$

where (g\in{0.045,0.060,0.080}) and (n) is the number of years elapsed since 2024–25. The three values are not assigned probabilities and should not be interpreted as policy targets.

5.4. Stock–Output Consistency Check

To examine the interaction between stock accumulation and output, the capital scenarios are paired with illustrative real-GSDP growth rates of 5.5%, 7.0% and 8.5%. The resulting NFCS/GSDP ratios are descriptive consistency checks. They do not constitute capital-output estimates or forecasts.

To assess the dependence of the terminal stock on the assumed accumulation rate, the scenario exercise should additionally report a continuous sensitivity grid covering annual NFCS growth rates from 3% to 9%, preferably in 0.5-percentage-point increments. This exercise does not imply that these rates are equally plausible; rather, it demonstrates the nonlinear effect of compounding and identifies the range of capital-stock outcomes associated with modest differences in sustained accumulation.

Table X: Aggregate post-2016–17 NFCS benchmark and annual growth

Financial year	Aggregate NFCS (₹ crore)	Annual growth	Status
2016–17	3,41,783.89	—	Inherited published PIM estimate
2017–18	3,55,980	4.15%	Author-updated benchmark
2018–19	3,72,650	4.68%	Author-updated benchmark
2019–20	3,89,720	4.58%	Author-updated benchmark
2020–21	4,02,880	3.38%	Author-updated benchmark
2021–22	4,24,350	5.33%	Author-updated benchmark
2022–23	4,49,120	5.84%	Author-updated benchmark
2023–24	4,75,850	5.95%	Author-updated benchmark
2024–25	5,02,565.85	5.61%	Author-updated benchmark

6. HISTORICAL EVIDENCE: 1980–2017

The original series records a more than threefold increase in aggregate NFCS. Primary NFCS rose from ₹12,624.57 crore in 1980–81 to ₹60,416.68 crore in 2016–17; secondary NFCS reached ₹82,221.32 crore; and tertiary NFCS reached ₹1,99,145.89 crore. Tertiary capital consequently became the largest component.

The original kinked-growth analysis identified 2005–06 as the aggregate turning point, with estimated growth increasing from 2.28% before the break to 8.08% afterward. Secondary capital growth increased from 2.29% to 5.14%, while tertiary-total growth increased from 1.57% to 10.54%. Primary capital had a separate turning point around 2000–01 [4]. The revised analysis now tests the inherited 2005–06 breakpoint on the full 1980–81 to 2024–25 benchmark. The Chow statistic of $F=300.44$ ($p<0.001$) provides strong evidence against a stable log-linear trend. A second test at 2017–18 gives $F=5.00$ ($p=0.011$), indicating statistically detectable trend instability in the updated period. These tests strengthen, but do not causally explain, the regime interpretation.

The interpretation should be cautious. The post-2005 acceleration is evidence of a changed accumulation regime, not proof that capital caused the subsequent growth acceleration. Nevertheless, the coincidence of faster capital accumulation and broader economic acceleration makes the period an important candidate for future causal analysis.

The estimated 2005–06 change should be interpreted as a descriptive regime shift in the NFCS trajectory. It does not establish that policy changes, infrastructure investment or sectoral transformation caused the acceleration. Capital accumulation may itself respond to contemporaneous output growth, expectations, public expenditure and private investment. Reverse causality and omitted variables therefore prevent causal interpretation of the kinked-growth estimates. The principal empirical claim is consequently restricted to the existence and magnitude of a change in the estimated capital-stock growth regime.

7. 2017–2025: A MODERATED ACCUMULATION REGIME

The updated benchmark indicates that aggregate NFCS increased by approximately 47% between 2016–17 and 2024–25, implying an endpoint CAGR of 4.94%. The annual benchmark growth rates range from 3.38% to 5.95%, showing continued accumulation with moderate volatility rather than a monotonic slowdown. Sectorally, primary capital increased from ₹60,416.68 crore to ₹84,960 crore, secondary capital from ₹82,221.32 crore to ₹1,16,520 crore, tertiary-I from ₹84,844.46 crore to ₹1,29,920 crore and tertiary-II from ₹1,14,301.43 crore to ₹1,71,166 crore. The tertiary share therefore rose modestly from 58.3% to 59.9% of aggregate NFCS, confirming the persistence of a service- and network-oriented capital structure. These calculations suggest compositional continuity with incremental deepening of tertiary assets, not a wholesale change in the sectoral hierarchy.

The source manuscript reports 2024–25 real GSDP of ₹5.31 lakh crore, real growth of 8.6%, secondary-sector share of 26.8%, tertiary share of 54.8% and primary share of 18.3%. GFCF was reported at ₹34,905 crore. The coexistence of stronger GFCF and slower NFCS growth illustrates why gross investment cannot be used as a proxy for net productive stock: depreciation, replacement investment, asset composition and retirement can absorb a substantial portion of gross additions.

Recent national evidence reinforces the importance of this distinction. India KLEMS separates capital stock from capital services and explicitly incorporates asset heterogeneity and efficiency profiles [3]. RBI research also cautions that utilisation affects measured productivity [11]. A Bihar capital database that aims at high-impact productivity research should therefore move beyond a single aggregate NFCS indicator.

The 2017–2025 period should be interpreted as a transition between the historical accumulation regime and the scenario horizon rather than as evidence of a permanent reduction in Bihar's investment potential. The

Period	Primary	Secondary	Tertiary-I	Tertiary-II	Tertiary total	Aggregate
1981–91	4.26	2.44	1.37	1.47	1.44	2.09
1991–2001	5.69	2.03	1.31	1.68	1.55	2.39
2001–11	4.44	3.99	8.61	5.31	6.55	5.47
2011–17	4.23	3.66	8.23	5.13	6.21	5.14

approximately 4.94% endpoint CAGR is calculated from two stock observations and therefore summarizes an endpoint change rather than estimating a complete post-2017 annual growth process. It may conceal substantial year-to-year variation in investment, depreciation and asset composition. Consequently, the evidence supports the statement that the endpoint stock increased substantially at a lower average rate than during the earlier high-accumulation regime, but it does not by itself identify the structural causes of the moderation.

8. CAPITAL COMPOSITION AND STRUCTURAL TRANSFORMATION

The large tertiary component of Bihar's capital stock should not be interpreted as evidence of an unproductive services bias. Transport, storage, communications, trade, finance, real estate, business services and urban infrastructure can raise the productivity of agriculture and manufacturing by lowering transaction costs and improving access to markets and finance. The relevant question is therefore whether tertiary assets generate cross-sectoral productivity spillovers.

At the same time, a services-led output structure does not automatically solve Bihar's employment challenge. Recent Indian evidence finds that many states have moved workers directly from agriculture into services while bypassing manufacturing, and that labour reallocation has contributed less to aggregate productivity growth than within-sector gains in many states [5, 6]. IMF evidence similarly identifies large productivity gaps between agriculture and other sectors and notes the importance of transport, land-market and labour-market constraints [7].

For Bihar, the implication is a complementary rather than sequential transformation strategy: raise agricultural productivity; create manufacturing and agro-processing capacity; develop logistics and energy systems; and expand productive services. This is consistent with evidence that manufacturing productivity can support service-sector productivity through spillovers [15] and that manufacturing expansion can generate demand for advanced services [16].

The dominance of tertiary capital should therefore be interpreted through a complementarity hypothesis rather than a sectoral ranking. Tertiary assets can raise the productivity of agriculture and manufacturing when they reduce transport, information, transaction and financing costs. Conversely, tertiary capital may generate relatively weak productive effects when complementary industrial, agricultural or human capabilities are absent. The relevant empirical question for future research is consequently whether the marginal productivity of tertiary

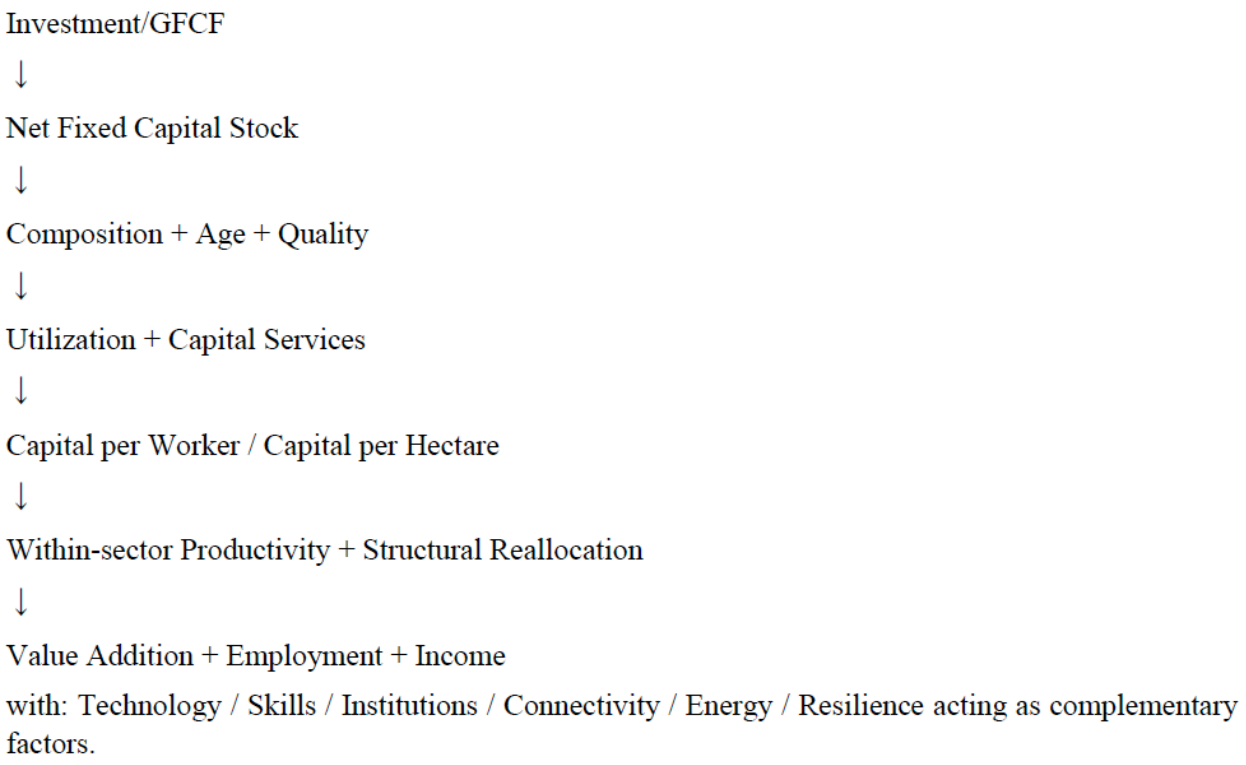


Figure 1: From Capital Accumulation to Capital Deepening: Analytical Transmission Framework.

capital is higher when it is combined with complementary primary and secondary capital. This interaction cannot be identified from aggregate NFCS data alone but provides a testable direction for a subsequent Bihar capital-services and productivity database.

Figure **1**. From capital accumulation to capital deepening: analytical transmission framework. The framework distinguishes the measured accumulation of fixed assets from the conditions through which accumulated capital may translate into productive capital services, capital deepening, productivity improvement, structural transformation and broader development outcomes. Technology, skills, institutions, connectivity, energy reliability and resilience are treated as complementary conditions rather than directly estimated determinants in the present study.

9. 2025–2050 CONDITIONAL CAPITAL PATHWAYS

2025–2050 Conditional Pathways include a scenario interpretation matrix.

The scenarios should not be interpreted as three alternative predictions about Bihar. They represent three internally consistent accumulation regimes. The economically relevant distinction is not simply the terminal stock but the institutional and productivity conditions required to sustain each regime. In particular, a higher stock trajectory would not necessarily imply higher welfare if additional assets are poorly allocated, underutilized or inadequately maintained.

The divergence is entirely consistent with compound growth. By 2050 the transformation pathway produces more than twice the stock of the conservative pathway. The result should not be read as a recommendation to pursue an 8% target mechanically. The economic value of additional capital depends on its productivity, utilisation, technology content, resilience and complementary skills.

10. OUTPUT CONSISTENCY AND CAPITAL-STOCK INTENSITY

The illustrative consistency test produces lower 2050 NFCS/GSDP ratios than the current descriptive ratio of 0.946 because output is assumed to grow faster than capital stock in all three paired scenarios. This arithmetic is important for interpretation. A falling K/Y ratio is not equivalent to declining capital deepening because capital deepening is conventionally defined in terms of capital services per unit of labour input, not the ratio of net wealth to output. Output can grow faster than the measured stock when utilization, capital quality, technology, labour quality or multifactor productivity improve. Conversely, a high K/Y ratio can coexist with weak productivity when capital is obsolete, underutilized or poorly allocated. The ratio is therefore retained as a consistency check rather than a productivity indicator.

The NFCS/GSDP ratio is used here as a descriptive capital-stock intensity indicator rather than as an estimate of capital productivity or a capital-output coefficient. A falling ratio can occur alongside rising productivity if output grows faster than the measured stock, but it can also reflect differences in asset valuation, depreciation, utilization or sectoral composition. Accordingly, the ratio

Scenario	Interpretation	Required enabling conditions	Main risk
4.5%	Continuation of moderate accumulation	Maintenance and selective expansion	Ageing/insufficient renewal
6.0%	Sustained broad-based accumulation	Higher private and public investment + productivity	Allocation inefficiency
8.0%	High-accumulation transformation pathway	Strong investment, utilization, technology and institutional capacity	Overinvestment/low returns if complements lag

Year	4.5% pathway	6.0% pathway	8.0% pathway
2030	₹6,26,288 crore	₹6,72,546 crore	₹7,38,434 crore
2035	₹7,80,469 crore	₹9,00,019 crore	₹10,85,002 crore
2040	₹9,72,607 crore	₹12,04,428 crore	₹15,94,224 crore
2045	₹12,12,045 crore	₹16,11,797 crore	₹23,42,438 crore
2050	₹15,10,429 crore	₹21,56,948 crore	₹34,41,810 crore

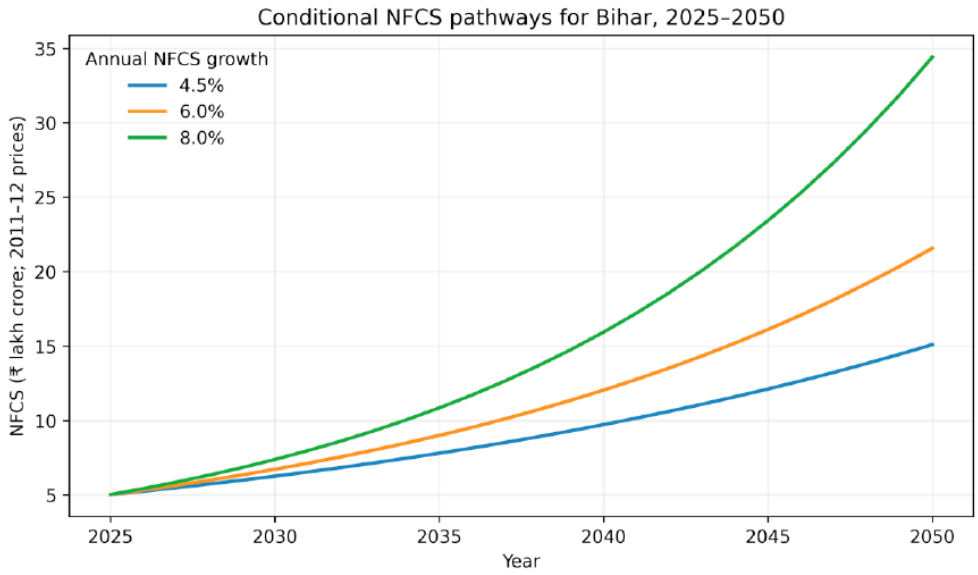


Figure 2: Conditional NFCS pathways from the author-updated 2024–25 benchmark at 2011–12 prices. The pathways are mechanical scenario calculations and are not forecasts or probability-weighted projections.

Pathway	NFCS growth	Real GSDP growth	2050 NFCS/GSDP
Conservative	4.5%	5.5%	0.745
Intermediate	6.0%	7.0%	0.748
Transformation	8.0%	8.5%	0.843

is used only as a consistency indicator for the scenario exercise. Estimating capital productivity would require capital services and a production or growth-accounting framework.

11. CAPITAL-DEEPENING MECHANISMS FOR BIHAR

Because the present database does not permit direct estimation of these indicators, they are proposed as an empirical monitoring framework for future assessment of whether accumulated capital is being converted into productive capital deepening.

11.1. Agriculture and Climate Resilience

Irrigation, drainage, flood management, mechanisation, storage, cold chains, fisheries infrastructure and post-harvest assets can raise agricultural productivity while reducing climate risk. This is particularly relevant because Bihar's official water-resources information identifies 68.80 lakh hectares as flood-prone, affecting 28 of 38 districts. Recurrent flooding can damage transport, irrigation, embankments, housing and productive assets and can therefore reduce the effective service flow of capital even when measured NFCS continues to rise. Capital deepening in agriculture should consequently be assessed through capital per hectare, yield, cropping intensity, post-harvest losses, disruption days and resilience outcomes. The scenario interpretation should treat resilience expenditure as partly productive replacement and service-preservation investment rather than as a purely defensive fiscal cost.

Empirically, agricultural capital deepening should be evaluated using capital per hectare, capital per agricultural worker, irrigation intensity, cropping intensity, yields and post-harvest loss. These indicators should be examined jointly because a higher capital stock without improved land or labor productivity may indicate underutilization rather than successful deepening.

11.2. Manufacturing and Agro-Processing

Manufacturing capital should include industrial estates, common facilities, food processing, textiles, engineering, packaging, testing, waste management and reliable electricity. The central objective is local value retention: transforming primary outputs into higher-value products and creating demand for services, logistics and skills.

Manufacturing capital deepening should be evaluated using capital per worker, manufacturing GVA per worker, capacity utilization, private fixed investment, electricity reliability and the share of processed output in total sectoral production.

11.3. Logistics and Market Access

Roads, railways, inland waterways, warehouses, cold chains and multimodal nodes should be evaluated as integrated networks. The relevant question is whether the network reduces travel time, logistics costs and uncertainty sufficiently to change firm location, market participation and investment decisions.

The productivity effect of logistics capital should be evaluated through travel time, logistics cost, market-access indicators, freight volumes and the spatial distribution of industrial and agricultural value addition.

11.4. Energy and Digital Capital

Reliable power, transmission, renewables, storage, broadband and digital public infrastructure are increasingly general-purpose productive assets. Their value depends on reliability, affordability, enterprise adoption and skills, not installed capacity alone.

11.5. Urban and Human Capital

Urban housing, water, sanitation, mobility, health and education infrastructure determine whether cities can absorb growing populations and firms. Skills, technical education, management capability and digital literacy should be treated as complements to physical capital rather than as separate social-sector concerns.

11.6. Green and Circular Capital

Pollution control, clean energy, water efficiency, waste recovery and circular production systems can protect the service flow of existing assets while lowering resource intensity. By 2040–2050, replacement and resilience investment should become increasingly important as the capital base ages.

12. POLICY ARCHITECTURE AND MEASURABLE LINKAGES

The policy implications are conditional on the empirical distinction between capital accumulation and capital deepening. The analysis does not imply that any particular category of expenditure automatically produces productivity gains. Instead, each investment category should be evaluated according to whether it increases productive capital services, reduces transaction costs, raises factor productivity, expands market access, increases resilience or enables complementary private investment. The monitoring equation is as follow:

$[CDI_t = w1\Delta(K/L)_t + w2\Delta LP_t + w3\Delta CU_t + w4\Delta TFP_t + w5\Delta MA_t]$

where:

(K/L) = capital per worker;

Policy pillar	Capital priority	Structural mechanism	Core indicator
Agriculture/resilience	Irrigation, drainage, storage, mechanisation	Higher land productivity and lower climate losses	Capital/ha; yield; post-harvest loss
Industrialisation	Industrial estates, power, common facilities	Firm scale and manufacturing value addition	Manufacturing GVA; private fixed investment; utilisation
Agro-processing	Cold chain, grading, processing, packaging	Local value retention	Processed share; producer price spread
Logistics	Road, rail, waterways, warehouses	Market access and lower transaction costs	Travel time; logistics cost
Energy	Generation, grid, renewable/storage	Reliability and production continuity	Outage hours; industrial power reliability
Digital	Broadband, data, digital public infrastructure	Information and service productivity	Firm adoption; digital intensity
Urban systems	Water, sanitation, housing, mobility	Urban productivity and absorption	Service quality; municipal revenue
Human capital	Skills, technical education, management	Capital utilisation and technology adoption	Skill completion; placement; productivity
Green capital	Clean energy, circular systems, pollution control	Resilience and resource productivity	Carbon/resource intensity

(LP) = labor productivity;

(CU) = capacity utilization;

(TFP) = total factor productivity;

(MA) = market-access indicator.

The proposed Capital-Deepening Monitoring Framework is a future empirical construct, not an estimate produced in this study. Equal weights (0.20 each) may be used only as a transparent baseline once the underlying indicators are available; they are not presented as empirically optimal weights. Alternative entropy, principal-component or policy-calibrated weights should be reported in future work. The minimum data requirements are explicit: annual NFCS and employment for K/L, sectoral GVA and employment for labour productivity, utilization surveys for capacity use, asset-specific capital services and labour services for TFP/growth accounting, and travel-time or network data for market access. This makes the index falsifiable and reproducible rather than rhetorical.

The policy architecture should be implemented in three windows. 2025–2030 should emphasise network completion, maintenance, capacity utilisation and project quality. 2030–2040 should emphasise scale, industrial diversification, agro-processing, logistics, energy and modern services. 2040–2050 should emphasise productivity, replacement, technological upgrading and resilience.

Budgeted capital expenditure, capital outlay, GFCF and NFCS should remain analytically distinct. The source manuscript reports substantial 2026–27 fiscal allocations for capital expenditure and capital outlay, but these are budgetary measures and cannot be substituted for realised economy-wide fixed capital formation or net capital stock.

13. SENSITIVITY, UNCERTAINTY AND FALSIFICATION STRATEGY

The revision converts several proposed robustness checks into explicit diagnostics. First, the complete benchmark series is subjected to Chow tests at 2005–06 and 2017–18. Second, the 4.94% endpoint CAGR is stress-tested under annual deflator differentials of −1.0, −0.5, 0, +0.5 and +1.0 percentage points, yielding an approximate CAGR range of 4.58%–5.32%. Third, the 2050 scenario is evaluated continuously over 3–9% annual NFCS growth in 0.5-point increments. Fourth, PIM-consistent gross-investment requirements are shown for the three headline pathways. These checks do not eliminate measurement uncertainty, but they identify which conclusions are robust to alternative trend, price-conversion and accumulation assumptions. A future sector-by-asset database should additionally test multiple-break methods, capital-service growth and complementarity effects.

14. DISCUSSION

The evidence supports a regime-based interpretation of Bihar's capital trajectory. The pre-2005 period represents a relatively low-accumulation regime; 2005/06–2017 represents a high-accumulation regime dominated increasingly by tertiary capital; and 2017–2025 represents continued accumulation at a lower endpoint growth rate. The key analytical error would be to extrapolate the post-2005 rate mechanically to 2050.

The second finding is that capital composition matters. Tertiary capital can support transformation by lowering

Uncertainty	Why it matters	Recommended test
Initial stock	Affects the entire level path	Alternative initial-stock benchmarks
Depreciation/lives	Changes net stock materially	Asset-specific schedules
Deflators	Can alter real stock growth	Asset-specific price indices
Asset composition	Different assets provide different services	Capital-service indices
Utilisation	Idle assets may inflate measured stock	Capacity-utilisation data
Structural breaks	Break dates may differ by sector	Formal multiple-break tests
GFCF-to-NFCS conversion	Gross additions are not net additions	Full annual investment/CFC schedules
Output assumptions	Change stock-output consistency	Alternative output/productivity scenarios
Climate/technology shocks	Can alter asset lives and productivity	Stress tests and retirement scenarios

transaction costs and increasing connectivity, but it cannot substitute completely for productive capacity in agriculture and manufacturing when the employment structure remains heavily dependent on agriculture. Recent Indian research demonstrates that labour reallocation alone has contributed modestly to productivity growth in many states, making within-sector productivity improvement equally important [5, 6].

The third finding is that capital deepening is a quality-adjusted concept. A larger stock can coexist with weak productivity if assets are obsolete, underutilised or poorly connected. Conversely, output can grow faster than stock when technology, utilisation and human capital improve. The policy objective should therefore be to raise the productive yield of capital rather than maximise gross investment mechanically.

Finally, Bihar's transformation should be understood as a networked process. Agricultural productivity, agro-processing, manufacturing, logistics, energy, digital systems and urban services create complementary demand and supply effects. This is more consistent with contemporary evidence than a linear agriculture→manufacturing→services model.

15. LIMITATIONS

- The 1980–2017 historical NFCS series is inherited from the author's earlier publication and is not fully re-estimated here.
- The 2024–25 NFCS is an author-updated benchmark. The supplementary workbook provides the annual benchmark and the explicit 5% aggregate-depreciation reconciliation; the implied real-investment schedule must not be interpreted as an independently observed official GFCF series.
- The 2050 pathways are conditional scenarios, not probabilistic forecasts.
- Constant growth rates within scenarios abstract from endogenous investment, demographic change, cyclical shocks, depreciation variation, technological change and climate events.
- NFCS is a wealth-stock concept and is not equivalent to productive capital services. Asset age, utilisation and composition can materially change productive capacity.
- The NFCS/GSDP ratio is descriptive and should not be interpreted as a causal capital-output coefficient.
- The 2005–06 break is corroborated by a full-series Chow test, but the test does not establish its economic cause; the 2017–18 test likewise identifies instability rather than causation.
- Employment and sectoral productivity data at the Bihar level are not integrated sufficiently to identify causal effects of capital accumulation on labour reallocation.
- Some recent national evidence is informative for Bihar but cannot be assumed to apply identically to the state; state-specific estimates are required.
- Measurement error
- Long historical PIM series may contain measurement error arising from changes in source definitions, sectoral classification, price indices and revisions to national-account methodology. Such uncertainty should be distinguished from sampling uncertainty because the NFCS is constructed rather than directly observed.
- Asset heterogeneity
- Aggregate depreciation rates may mask substantial differences in service lives and efficiency profiles across buildings, machinery, transport equipment, infrastructure and ICT assets. This limitation is particularly relevant when interpreting long-horizon changes in capital quality.
- Utilization
- The NFCS measure does not directly observe capacity utilization. A stock can increase while productive utilization falls, and measured productivity can change with utilization independently of the physical stock.
- Intangible capital
- The historical NFCS framework is primarily oriented toward fixed physical assets and therefore does not fully capture the growing role of software, organizational capital, data, research and development and other intangible assets. Contemporary capital measurement increasingly recognizes such assets, although their consistent state-level estimation remains difficult.

16. REPRODUCIBILITY AND FUTURE RESEARCH

Supplementary Tables **S1**–**S3** provide the annual investment/GFCF inputs, price-conversion procedures,

initial-stock and depreciation assumptions, sectoral aggregation rules, annual NFCS calculations, sensitivity tests and 2025–2050 scenario calculations. The preferred reproducibility standard is that an independent researcher should be able to reproduce every reported NFCS endpoint, growth rate, structural-break estimate and scenario value from the supplied files without access to unpublished calculations.

CONCLUSIONS

Bihar's capital trajectory is characterised by substantial long-run accumulation, a statistically supported regime changes around 2005–06, continued expansion after 2016–17, and a persistent dominance of tertiary capital. Aggregate NFCS rises from ₹3,41,783.89 crore in 2016–17 to ₹5,02,565.85 crore in 2024–25, an endpoint CAGR of 4.94%. The annual benchmark growth rates show variation but no evidence that the post-2005 acceleration can be extrapolated mechanically. The tertiary share rises modestly from 58.3% to 59.9%, suggesting continuity in the network- and service-oriented structure of Bihar's accumulated capital.

The 2050 scenarios demonstrate the consequences of compounding: 4.5%, 6.0% and 8.0% annual NFCS growth produce approximately ₹15.10, ₹21.57 and ₹34.42 lakh crore, respectively. The exercise is useful precisely because it is conditional. It quantifies the capital-stock consequences of alternative regimes without disguising assumptions as forecasts.

The principal implication is therefore not that Bihar should maximize capital accumulation, but that the productive return to accumulated capital depends on composition, utilization, connectivity, technology and complementary capabilities. A larger NFCS can create the potential for capital deepening, but that potential becomes economically meaningful only when capital services per worker and per unit of output increase alongside productivity and productive employment.

The 2050 scenarios illustrate the magnitude of this distinction. The difference between the conditional 4.5%, 6.0% and 8.0% pathways is generated mechanically by compounding, but sustaining any particular pathway would depend on investment behavior, depreciation, asset renewal, productivity, institutional capacity and complementary human and technological capabilities. The appropriate empirical objective for future Bihar research is therefore to move from an NFCS database toward an asset-specific capital-services and productivity database. Such an extension would permit direct testing of whether the changing capital structure identified in this study contributes to productivity growth and structural transformation.

The principal contribution is therefore a measurement-and-theory bridge: the paper documents the changing quantity and composition of Bihar's fixed-capital stock, establishes statistically supported accumulation regimes, and specifies the complementary conditions under which stock accumulation could become measurable capital deepening. The 2050 pathways should be read as conditional accounting experiments, not forecasts. Their value lies in showing that the long-run consequences of accumulation rates are large, while the productive value of those assets depends on utilization, composition, connectivity, skills, technology, resilience and allocation. The next empirical frontier is an asset-specific Bihar capital-services database capable of testing these mechanisms directly.

DECLARATIONS

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Conflict of Interest

The author declares no conflict of interest.

Data Availability

The historical NFCS series is based on the author's previously published methodology and source data. The updated calculations presented in this article are accompanied by supplementary files containing the annual investment/GFCF inputs, price-conversion procedures, PIM parameters, annual NFCS calculations, sensitivity tests and 2025–2050 scenario calculations. Source data that are subject to third-party restrictions are identified in the supplementary documentation.

Ethics

Not applicable.

AI-Use Statement

Generative AI was used only for language improvement, literature organisation and drafting assistance. The substantive empirical estimates, data selection, calculations, interpretation and responsibility for the manuscript remain with the author.

APPENDIX A. SCENARIO CALCULATION

K_{2025} = ₹5,02,565.85 crore at 2011–12 prices. $K_t = K_{2025}(1+g)^{(t-2025)}$.

Year	4.5%	6.0%	8.0%
2030	626,288.48	672,546.47	738,434.11
2035	780,469.40	900,018.89	1,085,001.98
2040	972,606.87	1,204,428.31	1,594,223.87
2045	1,212,045.11	1,611,796.76	2,342,437.89
2050	1,510,428.72	2,156,947.66	3,441,809.76

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