To cite this article: Jiarong Huang, Lixin Zhou*, Si Yi. (2026). *Has the Integration of Digital and Real Economies Promoted Green Innovation in the Yangtze River Economic Belt? Journal of Financial and Economic Dynamics*, 1(1), 1-20; https://doi.org/10.66361/jfed.46

Has the Integration of Digital and Real Economies Promoted Green Innovation in the Yangtze River Economic Belt?

Jiarong Huang[1], Lixin Zhou[2], Si Yi[3]*

[1] Jiarong Huang, School of New Media Art, Chongqing Finance and Economics College, Chongqing, P.R.China; Institute for Chengdu-Chongqing Economic Zone Development, Chongqing Technology and Business University, Chongqing , P.R. China;Interdisciplinary Research Team for Holistic Green and High-Quality Development, Chongqing Finance and Economics College, Chongqing, P.R.China;Research Center for the Development of Small and Medium-sized Enterprises, Chongqing Finance and Economics College, Chongqing ,P.R.China

[2] Lixin Zhou, Institute for Chengdu-Chongqing Economic Zone Development, Chongqing Technology and Business University, Chongqing , P.R. China

[3] Si Yi, Institute for Chengdu-Chongqing Economic Zone Development, Chongqing Technology and Business University, P.R.China;Chongqing Finance and Economics College, Chongqing, P.R.China

**Corresponding author: Li xin Zhou; lxzhou@ctbu.edu.cn*

Abstract: Against the backdrop of China's "Dual Carbon" goals and a globally evolving, increasingly sophisticated climate governance framework, clarifying how the integration of the digital and real economies (Digital-real Integration, DRI) drives green innovation (GIP) is critical to advancing sustainable development. Using panel data from 105 prefecture-level cities across the Yangtze River Economic Belt (YREB) over the period 2011–2021, this study applies fixed-effects, mediation, and moderation models to carry out empirical analysis. Our results indicate that DRI exerts a significant positive impact on GIP, largely through the cultivation of new quality productive forces. Moreover, environmental regulation and local government competition further amplify the positive effect of DRI on GIP, while government attention to digital development imposes a significant negative moderating influence. Heterogeneity analysis further shows that the promotional role of DRI is more notable in non-central cities and regions with relatively low entrepreneurial activity. This research confirms that DRI is not only a systemic transformation of the techno-economic paradigm but also a key mechanism to address "green imbalance" and promote coordinated regional transformation. These findings deliver empirical support and policy guidance for green digital development in similar river basins and economic zones around the world.

Keywords: Digital-real integration; Green innovation; New quality productive forces; Environmental regulation; Government competition.

1. Introduction

Over the past four decades, China has made remarkable strides in economic development. However, its long-standing extensive growth model, which is heavily dependent on factor inputs and scale expansion, has simultaneously given rise to enduring challenges, such as high energy consumption, worsening environmental pollution, and rising carbon emissions [1,2]. Against this backdrop, together with the formal proposal of China's "Dual Carbon" goals and the continuous consolidation of the global climate governance regime, promoting green innovation (GIP) has become imperative for achieving sustainable development [3]. GIP not only effectively alleviates environmental pressures through clean technologies and low-carbon processes [4,5] but also fosters the development of emerging industries, which in turn drives the transformation of the economic structure toward green and low-carbon paradigms [6,7]. As such, exploring a new development model that can deeply integrate modern technologies with the production system to provide systematic support for GIP is of particular urgency [8].

Over the past four decades, China has made remarkable strides in economic development. However, its long-standing extensive growth model, which is heavily dependent on factor inputs and scale expansion, has simultaneously given rise to enduring challenges, such as high energy consumption, worsening environmental pollution, and rising carbon emissions [1,2]. Against this backdrop, together with the formal proposal of China's

"Dual Carbon" goals and the continuous consolidation of the global climate governance regime, promoting green innovation (GIP) has become imperative for achieving sustainable development [3]. GIP not only effectively alleviates environmental pressures through clean technologies and low-carbon processes [4,5] but also fosters the development of emerging industries, which in turn drives the transformation of the economic structure toward green and low-carbon paradigms [6,7]. As such, exploring a new development model that can deeply integrate modern technologies with the production system to provide systematic support for GIP is of particular urgency [8].

Digital-Real Integration (DRI), which refers to the integration of the digital and real economies, is driving systemic transformations in production factors, productivity, and production relations [9] and thereby creating new pathways for GIP. Specifically, the deep permeation of digital technologies into the real economy [10] significantly enhances production efficiency [11,12], reduces business operational costs [13], and optimizes industrial structure [8]. This process in turn releases additional resources that can be directed towards GIP initiatives. According to data from the China Academy of Information and Communications Technology, the scale of China's digital economy reached 56.2 trillion yuan in 2024, accounting for 43.5% of GDP. Within this, the scale of industrial digitalization amounted to 46.1 trillion yuan, representing a year-on-year increase of 7.1%. The penetration rates of the digital economy into the agricultural, industrial, and service sectors have reached 11.2%, 26.3%, and 47.1%, respectively. This rapidly deepening integration process is increasingly becoming a vital driving force for GIP [9,14].

Existing studies have examined the links between the digital economy and environmental performance [15], sustainable development [11], green growth [7], and pollution and carbon reduction [16,17]. However, much of this literature still adopts a single "digital economy" perspective and pays limited attention to digital–real integration (DRI) as a process where digital technologies are embedded into the real economy and co-evolve with industrial systems. The relatively small body of DRI-oriented research tends to focus on the national or firm level, leaving a lack of systematic evidence at the river-basin economic system scale regarding whether and how DRI promotes green innovation (GIP) through identifiable transmission channels, as well as the institutional and governance contexts under which such effects vary. In particular, prior studies provide insufficient and inconsistent evidence on the mechanism pathways through which DRI affects green innovation. For example, they rarely clarify how DRI fosters new quality productive forces to enhance GIP and how contextual factors such as environmental regulation, local government competition, and government digital attention shape the boundary conditions of this relationship.

To address these gaps, this study takes the Yangtze River Economic Belt (YREB) as its empirical setting. Spanning 11 provinces and municipalities across eastern, central, and western China, the YREB accounted for 47.3% of the nation's GDP in 2024. It serves not only as China's most vital engine of economic growth [7] but also as a strategic ecological shield. The region exhibits pronounced spatial gradients: eastern cities are advanced in digital infrastructure and innovation capacity, while central and western areas face constraints in technology adoption and institutional support. Combined with the national policy directive of "prioritizing ecological conservation and prohibiting excessive development," the YREB offers an ideal quasi-natural experimental setting to investigate how DRI shapes GIP across diverse institutional and developmental contexts [18].

This study contributes in three main dimensions. First, theoretically, it moves beyond treating the digital economy merely as an external enabling tool by conceptualizing DRI as a co-embedded and restructuring process between digital technologies and real industries, and by elucidating the intrinsic mechanism through which DRI enhances GIP primarily via fostering new quality productive forces. By incorporating moderation analyses of environmental regulation, local government competition, and government digital attention, the study further clarifies the boundary role of institutional and governance contexts, enriching the theoretical understanding of green transition. Second, empirically, while existing work has largely concentrated on national- or firm-level evidence, this paper provides river-basin-scale evidence using a panel of 105 prefecture-level cities in the YREB. Third, from a policy and practical perspective, the findings indicate that DRI exerts a stronger promotional effect on GIP in non-central cities and regions with lower entrepreneurial activity, which highlights DRI's distinctive value in addressing "green imbalance" and fostering coordinated regional transformation. The results offer empirical support for the YREB's strategic principle of "prioritizing ecological protection and pursuing green development," and provide policy-relevant insights for other river basins and economic zones seeking synergistic digital and green transformation.

2. Literature Review

2.1 Digital-real integration (DRI)

Over the past four decades, China has made remarkable strides in economic development. However, its long-standing extensive growth model, which is heavily dependent on factor inputs and scale expansion, has simultaneously given rise to enduring challenges, such as high energy consumption, worsening environmental pollution, and rising carbon emissions [1,2]. Against this backdrop, together with the formal proposal of China's "Dual Carbon" goals and the continuous consolidation of the global climate governance regime, promoting green innovation (GIP) has become imperative for achieving sustainable development [3]. GIP not only effectively alleviates environmental pressures through clean technologies and low-carbon processes [4,5] but also fosters the development of emerging industries, which in turn drives the transformation of the economic structure toward green and low-carbon paradigms [6,7]. As such, exploring a new development model that can deeply integrate modern technologies with the production system to provide systematic support for GIP is of particular urgency [8].

Digital-Real Integration (DRI), which refers to the integration of the digital and real economies, is driving systemic transformations in production factors, productivity, and production relations [9] and thereby creating new pathways for GIP. Specifically, the deep permeation of digital technologies into the real economy [10] significantly enhances production efficiency [11,12], reduces business operational costs [13], and optimizes industrial structure [8]. This process in turn releases additional resources that can be directed towards GIP initiatives. According to data from the China Academy of Information and Communications Technology, the scale of China's digital economy reached 56.2 trillion yuan in 2024, accounting for 43.5% of GDP. Within this, the scale of industrial digitalization amounted to 46.1 trillion yuan, representing a year-on-year increase of 7.1%. The penetration rates of the digital economy into the agricultural, industrial, and service sectors have reached 11.2%, 26.3%, and 47.1%, respectively. This rapidly deepening integration process is increasingly becoming a vital driving force for GIP [9,14].

Existing studies have examined the links between the digital economy and environmental performance [15], sustainable development [11], green growth [7], and pollution and carbon reduction [16,17]. However, much of this literature still adopts a single "digital economy" perspective and pays limited attention to digital–real integration (DRI) as a process where digital technologies are embedded into the real economy and co-evolve with industrial systems. The relatively small body of DRI-oriented research tends to focus on the national or firm level, leaving a lack of systematic evidence at the river-basin economic system scale regarding whether and how DRI promotes green innovation (GIP) through identifiable transmission channels, as well as the institutional and governance contexts under which such effects vary. In particular, prior studies provide insufficient and inconsistent evidence on the mechanism pathways through which DRI affects green innovation. For example, they rarely clarify how DRI fosters new quality productive forces to enhance GIP and how contextual factors such as environmental regulation, local government competition, and government digital attention shape the boundary conditions of this relationship.

To address these gaps, this study takes the Yangtze River Economic Belt (YREB) as its empirical setting. Spanning 11 provinces and municipalities across eastern, central, and western China, the YREB accounted for 47.3% of the nation's GDP in 2024. It serves not only as China's most vital engine of economic growth [7] but also as a strategic ecological shield. The region exhibits pronounced spatial gradients: eastern cities are advanced in digital infrastructure and innovation capacity, while central and western areas face constraints in technology adoption and institutional support. Combined with the national policy directive of "prioritizing ecological conservation and prohibiting excessive development," the YREB offers an ideal quasi-natural experimental setting to investigate how DRI shapes GIP across diverse institutional and developmental contexts [18].

This study contributes in three main dimensions. First, theoretically, it moves beyond treating the digital economy merely as an external enabling tool by conceptualizing DRI as a co-embedded and restructuring process between digital technologies and real industries, and by elucidating the intrinsic mechanism through which DRI enhances GIP primarily via fostering new quality productive forces. By incorporating moderation analyses of environmental regulation, local government competition, and government digital attention, the study further clarifies the boundary role of institutional and governance contexts, enriching the theoretical understanding of green transition. Second, empirically, while existing work has largely concentrated on national- or firm-level evidence, this paper provides river-basin–scale evidence using a panel of 105 prefecture-level cities in the YREB. Third, from a policy and practical perspective, the findings indicate that DRI exerts a stronger promotional effect on GIP in non-central cities and regions with lower entrepreneurial activity, which highlights DRI's distinctive value in addressing "green imbalance" and fostering coordinated regional transformation. The results offer empirical support for the YREB's strategic principle of "prioritizing ecological protection and pursuing green development," and provide policy-relevant insights for other river basins and

economic zones seeking synergistic digital and green transformation.

The DRI has attracted growing attention from both academic and policy circles as a vital pathway for driving high-quality economic development [9]. Existing research has primarily evolved along three dimensions: conceptual clarification, identification of economic effects, and methodological evolution in measurement.

In terms of conceptual foundations, DRI is rooted in the theory of industrial convergence. Yoffie (1996) originally defined industrial convergence as a process through which digital technologies enable functional integration across products and services [19]. Curran et al. (2010) later expanded this notion and emphasized that convergence encompasses not only technological integration but also transformations in market structures, business models, and regulatory frameworks [20]. As the literature evolved, scholars began examining sector-specific manifestations of DRI. Hojeghan and Esfangareh (2011) investigated the integration of digital technologies into tourism [21], while Cheng and Zhou (2023) explored digital transformation pathways in agriculture. These studies collectively illuminate the contextual and sectoral nuances of DRI in practice [22].

More recently, a systemic perspective has gained traction. Sun et al. (2024a) characterized DRI as a dynamic, reciprocal interaction between the digital and real economies that fosters a virtuous cycle of co-evolution [5]. Meng (2023) further argued that DRI involves a systemic reconfiguration of traditional industrial systems through the infusion of data as a key production factor, digital technologies, and platform-based organizational models, which in turn enables comprehensive innovation and efficiency gains [8]. Building on this evolving understanding, this study conceptualizes DRI not merely as the adoption of digital tools but as a structural transformation driven by data and digital technologies, where digital industrialization and industrial digitization reinforce each other to reshape productivity, resource allocation, and innovation capacity across the economy.

Regarding its impacts, evidence has been documented across different levels of analysis. At the macro level, Hong and Ren (2023) found that DRI fosters the transformation and upgrading of the real economy through the embedding of data factors and the development of the platform economy [23]. Xin et al. (2023) demonstrated its strategic value for regional energy transitions [24], while Liu et al. (2024), using a national sample, confirmed its role in enhancing green development efficiency [9]. At the meso level, focusing on the industrial sector, Meng (2023) revealed its driving mechanisms for industrial green transformation [8]. At the micro level, Sun et al. (2024a) identified that DRI promotes industrial synergy through optimized information allocation, but they also noted potential new risks such as exacerbating capital market volatility [5].

In terms of measurement, prevailing methodologies primarily include patent analysis, input-output analysis, and the coupling coordination degree model. Patent analysis focuses on technological convergence. Gambardella and Torrisi (1998) pioneered the use of the Herfindahl-Hirschman Index (HHI), measuring industrial convergence by calculating the share of technology patents within an industry [25]. Fai and von Tunzelmann (2001) subsequently refined this approach by employing correlation coefficients of patents across industries to assess convergence levels [26]. The input-output analysis method was applied by Guerrieri and Meliciani (2004) to U.S. input-output tables to analyze linkages between producer services and manufacturing [27]. Meng (2023) later extended this method to measure the integration between the digital industry and the industrial sector [8]. Currently, the coupling coordination degree model is a more commonly employed assessment tool. Grounded in industrial synergy theory, it constructs indicator systems for the digital economy and the real economy respectively, and calculates the coupling coordination degree between these two subsystems to reflect the level of integration [5,9].

2.2 Green innovation (GIP)

Unlike traditional innovation, GIP is characterized by its dual attributes of environmental sustainability and technological advancement [5,6]. Chen et al. (2006) defined GIP as the innovation of hardware or software related to green products or processes, including technological advancements in energy conservation, pollution prevention, waste recycling, green product design, and corporate environmental management [28]. Saunila et al. (2018) also emphasized that GIP focuses on resource efficiency and environmental protection, primarily in technology and processes [29]. Some scholars have expanded the scope of GIP beyond product-level advancements to include innovations in processes, services, and management. This broader perspective not only aims to enhance corporate value but also seeks to reduce negative environmental impacts [30], which in turn achieves a harmonious balance of economic, social, and ecological benefits [31].

Academic research on the factors influencing GIP is extensive, with a primary focus on two key areas. The first area includes macro-level factors such as environmental regulations and pollution charges. For instance, Wagner (2007) found that environmental regulations in Germany negatively impacted the number of green patents in manufacturing firms [32]. In contrast, other scholars, such as Li et al. (2016) demonstrated that regulatory pressures, including environmental regulations and pollution charges, positively influence corporate GIP [33,34].

Research has also explored the effects of policies such as digital finance and carbon tariffs on GIP [35,36]. The second area focuses on micro-level factors within enterprises. Studies in this domain have examined how factors such as corporate governance, supply chain management, corporate social responsibility, and leadership capabilities influence GIP [37,38].

2.3 Relationship Between DRI and GIP

Empirical evidence directly linking DRI to GIP remains relatively limited. Existing literature has predominantly focused on the unidirectional effect of the digital economy or digital technologies on green innovation, and these studies can be categorized into three distinct strands for clearer comparison.

First, an efficiency–cost perspective (predominantly positive findings). Most studies have suggested that the digital economy significantly promotes GIP by improving information matching and factor allocation efficiency, reducing search and transaction costs, and facilitating financing and the organization of innovation resources [5,9,11,35]. Recent research has further refined the underlying mechanisms, highlighting channels such as resource allocation efficiency, debt financing costs, industrial-structure coordination, and firm digital transformation. In the YREB context, Luo et al. (2022) also confirmed the positive role of digital development in enhancing green innovation, while noting that the magnitude of this effect varies across cities [7].

Second, a collaboration–network and spillover perspective (emphasizing spatial interdependence). This strand argues that digitalization strengthens platform-enabled coordination, supply-chain linkages, and green knowledge diffusion, thereby fostering green innovation with notable externalities. Spatial-econometric evidence often documents significant spatial spillovers of the digital economy on green innovation (or green innovation efficiency) and industrial green innovation efficiency.

Third, an energy-constraint and nonlinearity perspective (highlighting a potential "green paradox" of digitalization). Beyond the "digital dividend," some studies caution that the energy consumption associated with digital infrastructure construction, equipment operation and maintenance, as well as rebound effects, may offset emission-reduction gains, resulting in diminishing marginal impacts or threshold and nonlinear patterns [39,40]. Related research also finds that digitalization has been more strongly associated with rising energy use at the aggregate level, which urges a more cautious interpretation of its net green effect [41].

In contrast, research explicitly examining the DRI–GIP nexus is still in its nascent stage and remains fragmented across different levels of analysis. A more structured view can be developed by differentiating evidence at the macro–meso–micro levels:

- ***Macro (urban/regional) level:*** Studies have begun to measure DRI using coupling-coordination or composite indices and test its effect on urban green innovation using two-way fixed effects, threshold models, and spatial Durbin specifications, documenting both positive impacts and spillover characteristics [9,42].
- ***Meso (industry/sector) level*****:** Based on industrial sector panel data, evidence suggests that DRI can promote industrial green transformation, with mechanisms linked to technological progress and structural optimization [8,24].
- ***Micro (firm) level*****:** Closely related evidence at the micro level comes from firm digital transformation, IT–industrialization integration, and the industrial internet. This body of research generally supports the idea that embedding digital technologies into production and management processes enhances both the quantity and quality of green innovation, partly by alleviating financing constraints and information asymmetry [5,43,44].

Overall, while the literature provides useful insights, three gaps remain: (i) the incremental effect of DRI beyond "digital economy" development is not fully disentangled; (ii) competing transmission channels from DRI to GIP have not been systematically compared; and (iii) boundary conditions, spatial spillovers, and within-belt gradients (e.g., the YREB's internal heterogeneity) are still underexplored. Motivated by these gaps, this study offers more systematic evidence on the DRI–GIP nexus at the river-basin scale through mechanism, moderation, and heterogeneity analyses.

1.4 Research Gap and Contributions

While prior research has examined the determinants of GIP and the relationship between the digital economy and GIP, literature specifically investigating the connection between DRI and GIP remains limited. Crucially, the pathways through which DRI influences GIP have not been adequately explored. Therefore, building upon existing literature, this study systematically analyzes the direct impact of DRI on GIP, along with its underlying mediation mechanisms, moderation mechanisms, and effect heterogeneity.

3. Theoretical Analysis and Research Hypotheses

3.1 Direct Impact of DRI on GIP

The advancement of GIP faces significant dual lock-in effects: it is constrained not only by technological lock-in associated with conventional production technologies and capital stocks but also by market lock-in linked to the acceptance of green products and policy continuity [45].

The DRI addresses these challenges through three key theoretical mechanisms. First, from the perspective of new classical growth theory, DRI significantly improves the allocation efficiency of traditional production factors, including capital and labor [46]. This improvement in efficiency releases substantial economic surplus previously trapped in inefficient sectors, thereby creating a valuable resource pool to underpin the high-risk, long-cycle research and development activities that characterize GIP. Second, consistent with endogenous growth theory [47], DRI substantially strengthens knowledge spillover effects. Digital platforms break down geographical and organizational boundaries, facilitating the rapid, low-cost dissemination of green technological knowledge, R&D experience, and best practices across broader domains. This digital-network-facilitated knowledge diffusion significantly reduces the learning costs for latecomer firms, which may accelerate the iteration and widespread adoption of green technologies within the YREB. Finally, from the perspective of transaction cost economics, information asymmetry constitutes a major obstacle to collaborative innovation [48,49]. By leveraging technologies such as big data and blockchain, DRI helps build transparent, traceable information systems that effectively mitigate information asymmetries. This not only reduces the costs associated with searching for partners and evaluating technological solutions but also enables automated execution mechanisms, including smart contracts, thereby expanding the collaborative frontier for GIP.

Within the specific context of the YREB, these direct effects are particularly pronounced. As a key corridor for heavy and chemical industries in China, the region has a heavy industrial structure, faces immense environmental pressure, and undertakes an arduous task of green transformation. Furthermore, spanning eastern, central, and western China, the region exhibits significant internal developmental disparities. DRI can effectively integrate industrial data across the YREB's upper, middle, and lower reaches, facilitating the intelligent and green upgrading of traditional sectors such as steel and chemicals.

Based on the above analysis, we propose the following hypothesis.

H1: DRI exerts a significant promoting effect on GIP within the YREB.

3.2 Mediating Mechanisms of DRI on GIP

NQP represents an advanced form of productivity that breaks free from dependence on traditional growth paths, essentially characterized by revolutionary technological breakthroughs, innovative allocation of production factors, and in-depth industrial transformation [50]. Through DRI, the in-depth integration of digital technologies such as artificial intelligence and big data into the real economy not only improves production efficiency [10] but also fosters intelligent R&D models and coordinates industrial chains. This directly drives the emergence of disruptive technologies and the optimization of industrial structures [7], thereby positively promoting the formation and development of NQP.

NQP plays a unique role in promoting GIP. First, its core attributes—technological progress and efficiency improvements—significantly lower the research, development, and application costs of green technologies, thereby enhancing the economic feasibility of GIP [51]. Second, NQP's emphasis on total factor productivity growth requires coordinated development between economic activities and the ecological environment. This inherent green orientation systematically directs innovation resources to green technology sectors [52]. Finally, within the YREB, the development of NQP is reshaping the regional industrial landscape. Industrial clusters such as smart manufacturing in the Yangtze River Delta, electronic information in the Chengdu-Chongqing region, and optoelectronics in Wuhan all exhibit strong GIP vitality. This trend is transforming GIP from an external constraint into a strategic choice for firms pursuing high-quality development. Thus, we propose the following hypothesis.

H2: NQP plays a positive mediating role in the impact of DRI on GIP.

3.3 Moderating Mechanisms of DRI on GI

3.3.1 The Moderating Role of Environmental Regulation (ENR)

The overarching principle guiding the development of the YREB is "prioritizing ecological protection over large-scale development." This strategic orientation is reinforced by a robust environmental regulatory framework that includes central environmental inspections and the Yangtze River Protection Law, which provides an ideal context for examining the Porter Hypothesis [53]. Within this institutional context, ENR enhances the impact of DRI on GIP through multiple pathways. First, it generates a demand-pull effect: stringent emission standards compel firms to prioritize the application of DRI outcomes in areas such as energy conservation and emission reduction [7]. Second, it generates an innovation compensation effect: compliance-

related cost savings, such as reductions in carbon taxes, along with potential brand premiums, can transform GIP from a cost center into a profit center [54]. Third, it generates a risk reduction effect: the stable policy expectations stemming from the "prioritizing protection" strategy reduce the institutional risks perceived by firms, which in turn encourages long-term R&D investments in green technologies.

Based on the above analysis, we propose the following hypothesis.

H3: ENR plays a positive moderating role in the relationship between DRI and GIP.

3.3.2 The Moderating Role of Local Government Competition (LGC)

Within China's fiscal decentralization system, LGC has long been centered on GDP growth as its primary goal. Since 2012, with the inclusion of ecological civilization construction in the performance evaluation system, the logic of inter-local competition has gradually shifted from a singular focus on economic growth to embracing multi-dimensional goals, including ecological performance. This shift is particularly evident in the YREB, where the overarching strategy of "prioritizing ecological protection and pursuing green development" has driven institutional and policy innovations focused on green and low-carbon development. Cities are competing to position themselves as smart cities, zero-waste cities, and dual-carbon demonstration zones, and implementing specialized support policies. Such benign competition not only enhances the institutional environment for green digital projects but also promotes the cross-regional flow of innovative factors, including technology, capital, and talent [55]. This, in turn, helps amplify the incentive effect of DRI on GIP. On the one hand, local governments adopt measures such as fiscal subsidies, land use guarantees, and data openness to reduce the costs for firms engaged in digital and green transitions [56]. On the other hand, demonstration practices in more advanced regions speed up the diffusion of green digital governance experiences to midstream and upstream cities [57], thereby improving overall synergistic efficiency.

Consequently, LGC—instead of merely triggering a race to the bottom—acts under institutional constraints and learning mechanisms as a significant contextual condition that magnifies the green effects of DRI.

Based on the above analysis, the following hypothesis is proposed.

H4: LGC plays a positive moderating role in the relationship between DRI and GIP.

3.3.3 The Moderating Role of Government Digital Attention (GEA)

The allocation of government attention is a key prerequisite for scientific decision-making and effective governance [58]. Within China's decentralization framework and central-local relations, local governments face multiple policy objectives and performance constraints; their attention allocation shapes the choice of policy instruments and resource allocation, which in turn influences firms' expectations and innovation behaviors [59,60]. From the perspective of the attention-based view, organizational actions, including those of governments are driven by the direction of limited attention toward certain issues, a process that may strengthen selected agendas while crowding out attention and resources from other equally important areas [61]. Accordingly, when government digital attention (GDA) is excessively focused on "digital economy or digital industry" agendas, it may diminish the marginal benefits of digital-real integration (DRI) to green innovation performance (GIP).

First, specifically, the negative moderating effect of GDA may operate through three channels:

The allocation of government attention is a key prerequisite for scientific decision-making and effective governance [58]. Within China's decentralization framework and central-local relations, local governments face multiple policy objectives and performance constraints; their attention allocation shapes the choice of policy instruments and resource allocation, which in turn influences firms' expectations and innovation behaviors [59,60]. From the perspective of the attention-based view, organizational actions, including those of governments are driven by the direction of limited attention toward certain issues, a process that may strengthen selected agendas while crowding out attention and resources from other equally important areas [61]. Accordingly, when government digital attention (GDA) is excessively focused on "digital economy or digital industry" agendas, it may diminish the marginal benefits of digital-real integration (DRI) to green innovation performance (GIP).

Target bias and resource crowding-out. When local governments prioritize highly visible, fast-return digital agendas (such as digital-economy hubs, digital government and smart cities, computing-power and data-center projects), scarce fiscal funds, land quotas, credit support, and talent policies may be allocated disproportionately to digital projects. This crowds out firms' long-term green R&D investments and experimental space. This "digital-first, green-constrained" resource reallocation can weaken the actual positive impact of DRI on GIP [61,62].

Second, administrative intervention and strategic innovation. When digitalization indicators and earmarked funds become key performance levers, governments may steer firms' technology choices through administrative guidance or subsidy bias, thereby shifting innovation toward policy-aligned trajectories rather than market-driven green technologies [59,61,62]. Meanwhile, stronger policy support may lead to strategic (symbolic) innovation, where firms prioritize label-driven projects to secure subsidies and preferential resources replacing substantive green technological breakthroughs with mere formal compliance [62].

Third, policy uncertainty and investment delay. Rapid digital technology iteration and frequent regulatory and policy adjustments may increase policy uncertainty, which strengthens firms' real-options "wait-and-see" incentives and deters long-cycle, high-cost, and more irreversible green R&D investment [63,64]. Prior studies have documented that policy uncertainty inhibits investment and innovation; in the green sector, uncertainty surrounding subsidy policies can also reduce firms' green R&D and inputs into green innovation [64,65].

H5: GDA plays a negative moderating role in the relationship between DRI and GIP. The conceptual framework for the empirical analysis is shown in Fig 1.

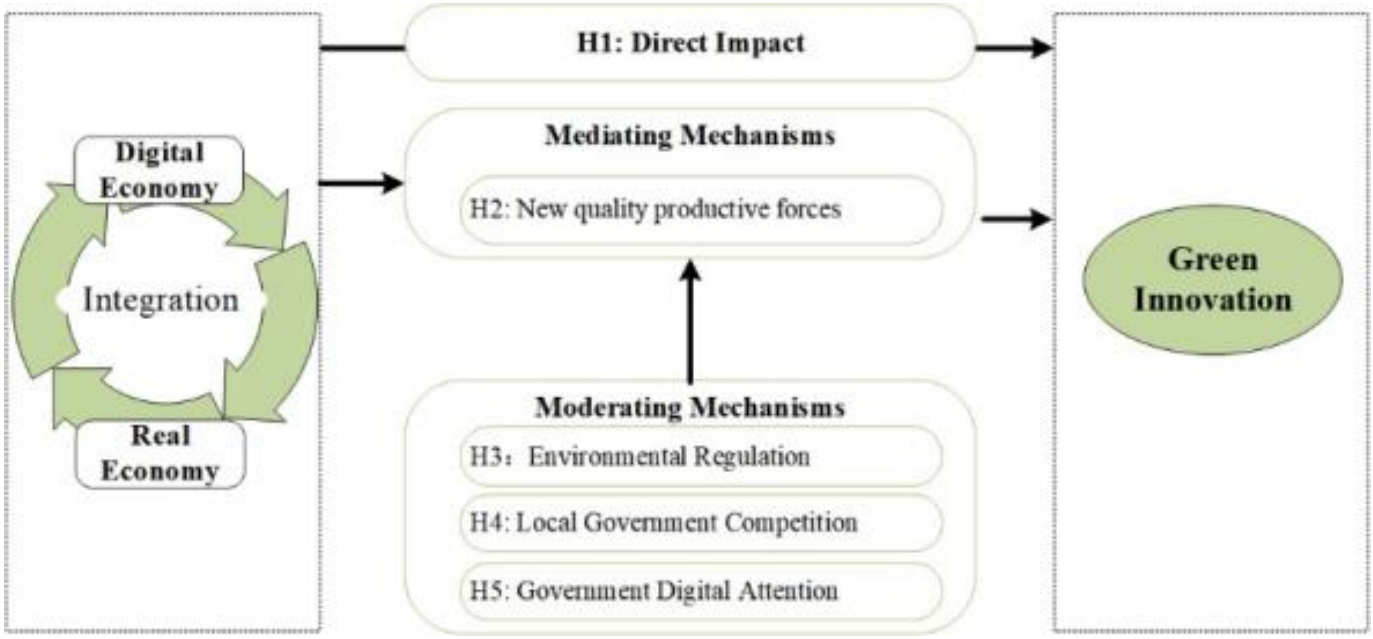


Fig 1. Conceptual framework for the empirical analysis

4. Empirical Research Design

4.1 Variable Selection

4.1.1 Core Explanatory Variable (DRI)

DRI involves an interactive association between two subsystems: the digital economy and the real economy. To measure the degree of this integration, this study adopts the methodologies proposed by Sun et al. (2024) and Liu et al. (2024), using a coupling coordination degree model to quantify DRI [5,9]. This measurement requires a prior assessment of the development status of both component subsystems.

For the Digital Economy subsystem (De), this study adopts the framework developed by Zhao et al. (2022), which includes indicators such as internet penetration rate, the number of employees in internet-related industries, the size of the mobile internet market, internet-related output, and the development of inclusive digital finance [66]. Regarding the Real Economy subsystem (Re), and taking into account data availability constraints at the municipal level, this study adopts the approach proposed by Xu et al. (2025) and Huang et al. (2024). This framework assesses the development level of the real economy from three dimensions: development scale, structural characteristics, and economic benefits [42,67]. Details of the hierarchical indicators are presented in Table 1

Table 1 Evaluation index system for the digital economy subsystem and the real economy subsystem

First-Level Indicator	Second-Level Indicator	Third-Level Indicator
De	Internet Penetration Rate	Number of Internet Users per Hundred People
	Number of Internet-Related Employees	Computer Services and Software Employees to Total

		Employees Ratio
	Internet-Related Output	Telecommunications Business Volume per Capita
	Mobile Internet Market Size	Number of Mobile Phone Users per Hundred People
	Inclusive Development of Digital Finance	China Digital Inclusive Finance Index
Re	Development Scale	Value Added of the Secondary Industry to GDP
		Total Retail Sales of Consumer Goods to GDP
	Development Structure	Non-Agricultural Employees to Total Employees Ratio
	Economic Benefits	Profits of Large-Scale Industrial Enterprises to Sales Revenue

After establishing the assessment framework for De and Re, the entropy method is used to calculate the development levels of the two subsystems [68], respectively. With the measured development levels of both subsystems, the Coupling Coordination Degree Model (Equations 1 and 2) is then utilized to further determine the level of DRI in the YREB, referred to as DRI:

$$C_{dr} = 2\sqrt{De \times \mathrm{Re}} / (De + \mathrm{Re}) \quad (1)$$

$$DRI = \sqrt{C_{dr} \times (\alpha De + \beta \mathrm{Re})} \quad (2)$$

In Equation (2), α and β denote the weights of the digital and real economies, respectively, with the condition α + β = 1. For this paper, it is set that both α and β are assigned the value of 0.5 [68].

4.1.2 Dependent Variable (GIP)

Following prior established literature (Li et al., 2024), we measure GIP activity by using the total number of green patent applications at the city level. The data are obtained from the Green Patent Classification Database of the China National Intellectual Property Administration. To address the issues of right-skewed distribution and heteroscedasticity, the raw application data are transformed through the natural logarithm after adding 1.

4.1.3 Mediating Variables: New quality productive forces (NQP)

To avoid potential overlap with indicators already incorporated into the DRI evaluation system, this study uses the frequency proportion of NQP-related expressions in local government work reports as a proxy for NQP. As " new quality productive forces" first emerged in Chinese policy agenda and governance discourse as a policy-driven concept, government work reports can effectively reflect local governments' attention to this development direction and their corresponding policy supply orientation. Based on the conceptualization of NQP proposed by Zhou et al. (2023) [69], we construct a keyword dictionary covering three dimensions: frontier technologies and innovation breakthroughs, industrial forms and structural upgrading, and high-quality development and efficiency improvement. We then employ text-based measurement on government work reports to capture regional-level NQP.1

4.1.4 Moderating Variables

Environmental Regulation (ENR): Following Meng et al. (2024), we perform textual analysis on government work reports of prefecture-level cities. The intensity of environmental regulation is proxied by the frequency of keywords including environmental protection, pollution control, and other related terms, as a proportion of the total text length [42,70,71].

Local Government Competition (LGC): This indicator captures the catch-up behavior of local officials motivated by performance evaluation under China's fiscal decentralization system. As the evaluation system places growing emphasis on green and low-carbon development, the competition paradigm has shifted from a singular focus on GDP growth to the integration of sustainable development objectives. Following the method proposed by Yue and Han (2025), the competition index is constructed based on the lead of a locality's economic growth rate over its neighboring regions. A higher value signifies a stronger sense of development urgency and more intense competitive activities [60].

Government Digital Attention (GDA): The annual average search frequency of keywords including digital economy and digital transformation for each prefecture-level city in the Baidu Index is employed as a proxy variable [72,73]. This measure captures local governments' policy focus and public attention towards digital development initiatives.

4.1.5 Control Variables

To mitigate potential omitted variable bias, we choose a series of control variables commonly employed in prior studies, encompassing economic level, population density, openness to foreign investment, urbanization rate, financial development level, and educational expenditure.

Economic Density (ECO): Economic level is measured as the ratio of regional GDP to the land area of the administrative jurisdiction, which is then transformed through the natural logarithm [42].

Population Size (POP): Population density is represented by the natural logarithm of the registered population, which controls for the impact of population size on innovation activities [9].

Financial Development Level (FIN): It is measured as the year-end balance of deposits and loans of financial institutions as a proportion of regional GDP, which reflects the regional financial support capacity.

Openness Level (OPE): Calculated as the ratio of actually utilized foreign direct investment to regional GDP [8,9].

Urbanization Rate (URB): Urbanization rate is defined as the proportion of the non-agricultural registered population to the total registered population, which captures the agglomeration effects and environmental pressures related to urbanization.

Educational Investment Level (EDU): Educational expenditure is represented as the proportion of local government educational expenditure in the general public budget expenditure, which reflects the foundational role of human capital accumulation in supporting innovation activities.

4.2 Model Specification

4.2.1 Direct Effect

To examine the direct impact of DRI on GIP in the YREB (H1), the following baseline model is constructed:

$$GIP_{it} = \alpha_0 + \alpha_1 DRI_{it} + \alpha_2 C_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

In Equation (3), GIP_{it} represents the GIP level of city i in year t, DRI_{it} denotes the DRI level of city i in year t, and C_{it} is a vector of control variables. The terms μ_i and δ_t represent city and year fixed effects, respectively, and ε_{it} is the random error term.

4.2.2 Mediation Effect

To verify the mediation effects (H2), mediation models are built upon Equation (3):

$$Me_{it}=\beta_0+\beta_1 DRI_{it}+\beta_2 C_{it}+\mu_i+\varepsilon_{it} \quad (4)$$

$$GIP_{it}=\gamma_0+\gamma_1 DRI_{it}+\gamma_2 Me_{it}+\gamma_3 C_{it}+\mu_i+\delta_t+\varepsilon_{it} \quad (5)$$

In Equations (4) and (5), Me_{it} represents the mediating variable. All other variables are defined consistently with Equation (3).

4.2.3 Moderation Effect

To investigate the moderation effects (H3-H5), interaction terms between DRI and the moderating variables are incorporated into Equation (3), establishing the following moderation model:

$$GIP_{it}=\sigma_0+\sigma_1 DRI_{it}+\sigma_2 Mo_{it}+\sigma_3 DRI_{it}\times Mo_{it}+\sigma_4 C_{it}+\mu_i+\delta_t+\varepsilon_{it} \quad (6)$$

In Equation (6), Mo_{it} represents the moderating variable, and $DRI_{it}\times Mo_{it}$ is the interaction term between the core explanatory variable and the moderating variable. All other variable definitions remain consistent with Equation (3).

4.3 Data Sources and Descriptive Statistics

The data for DRI are obtained from the measurements described in the preceding sections. The data for GIP are obtained from the China National Intellectual Property Administration. Other relevant data are collected from sources such as the China City Statistical Yearbook and various local statistical bulletins. The descriptive statistics for all variables are provided in detail in Table 2.

Table 2 Descriptive Statistics of Variables

Variable	N	Mean	SD	Min	p50	Max
GIP	1155	5.402	1.660	1.099	5.283	9.876
DRI	1155	0.312	0.081	0.143	0.294	0.610
ECO	1155	7.562	1.089	4.432	7.463	11.13
POP	1155	6.046	0.615	4.301	6.131	8.136
FIN	1155	2.458	0.959	0.764	2.254	6.559
OPE	1155	0.003	0.003	0.000	0.002	0.014

URB	1155	0.334	0.176	0.0752	0.287	0.996
EDU	1155	0.173	0.030	0.044	0.171	0.267

5. Analysis of Empirical Results

5.1 Direct Effects

5.1.1 Baseline Regression Results

Table 3 reports the baseline regression results for the impact of DRI on GIP. Column (1) presents the results of the baseline model, which includes only the core explanatory variable. Column (2) adds the series of control variables to the model from Column (1). Columns (3) to (5) sequentially adopt ordinary standard errors, robust standard errors, and standard errors clustered at the city-year level.

In Column (5), the estimated coefficient of DRI is 2.148, which is statistically significant at the 1% level. This indicates that a one-unit increase in DRI leads to a significant 2.148-unit increase in a city's GIP, confirming the direct promotional effect of DRI on GIP. Thus, Hypothesis 1 (H1) is supported.

Table 3 Baseline Regression Results

Variables	(1)	(2)	(3)	(4)	(5)
	GIP	GIP	GIP	GIP	GIP
DRI	15.980***	5.027***	2.148***	2.148***	2.148***
	(42.359)	(10.216)	(3.374)	(3.599)	(3.599)
ECO		0.756***	0.771***	0.771***	0.771***
		(19.766)	(7.385)	(7.656)	(7.656)
POP		0.760***	0.315	0.315	0.315
		(20.073)	(1.570)	(1.632)	(1.632)
FIN		0.290***	0.129***	0.129***	0.129***
		(10.072)	(2.830)	(2.850)	(2.850)
OPE		28.513***	3.956	3.956	3.956
		(3.505)	(0.462)	(0.457)	(0.457)
URB		-0.314*	-0.192	-0.192	-0.192
		(-1.815)	(-0.677)	(-0.672)	(-0.672)
EDU		-4.691***	-0.664	-0.664	-0.664
		(-6.277)	(-1.065)	(-1.084)	(-1.084)
City fixed	No	Yes	Yes	Yes	Yes
Year fixed	No	Yes	Yes	Yes	Yes
_cons	0.422***	-6.361***	-3.154*	-3.154*	-3.154*
	(3.476)	(-24.960)	(-1.832)	(-1.820)	(-1.820)
N	1155	1155	1155	1155	1155
R^2	0.609	0.828	0.973	0.973	0.973
* p < 0.1, ** p < 0.05, *** p < 0.01					

5.1.2 Robustness Checks

First, replacing the Explanatory Variable: An alternative DRI indicator (DRIP) was developed at the technology fusion dimension based on patent citation data. As shown in Column (1) of Table 4, the estimated coefficient of DRIP on GIP is 0.038, which is statistically significant at the 5% level, confirming that Hypothesis 1 (H1) remains robust.

Second, Replacing the Dependent Variable: The measure of GIP was substituted with the number of green invention patent applications (GIP1). As presented in Column (2) of Table 4, the results show that the estimated coefficient of DRI on GIP1 is 3.007 and remains statistically significant, which confirms that this robustness check is passed.

Third, Adjusting the Sample Range: Considering the potential structural impact of the COVID-19 pandemic on innovation activities after 2020, we re-estimated the model based on the 2011–2019 sub-sample [74]. As

shown in Column (3) of Table 4, the results indicate no significant change in the direction or statistical significance of the coefficient of the core explanatory variable, which further confirms the robustness of the baseline results.

Table 4 Robustness Check Results

Variables	(1)	(3)
	GIP	GIP
DRIP	0.038**	
	(2.322)	
DRI		2.101***
		(3.067)
_cons	-3.077*	-1.054
	(-1.774)	(-0.477)
Control	Yes	Yes
City fixed	Yes	Yes
Year fixed	Yes	Yes
N	1155	945
R^2	0.973	0.973
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$		

5.1.3 Endogeneity Tests

To address potential empirical endogeneity concerns between DRI and GIP, this study adopts an instrumental variable (IV) approach. We chose robot installation density (Rob) and the one-period lagged term of DRI (L.DRI) as instrumental variables. As reported in Table 5, the relevant test findings are presented in detail.

First, using Robot Installation Density as the IV: The first-stage results in Column (1) reveal a statistically significant coefficient of Rob on DRI at the 1% level, which satisfies the relevance condition. The Kleibergen-Paap rk Wald F statistic is 16.997, which is greater than the Stock-Yogo critical value of 16.38. Additionally, the Kleibergen-Paap rk LM statistic is statistically significant at the 1% level, which rejects concerns about weak instruments and underidentification. The second-stage results in Column (2) reveal a DRI coefficient of 9.682 that is statistically significant at the 10% level, which further validates the baseline conclusion.

Second, using the Lagged Term as the IV: The first-stage regression results in Column (3) reveal a coefficient of L.DRI of 0.449, which is statistically significant at the 1% level, which again supports the relevance of the instrument. The weak instrument test F-statistic is 58.165, which is well above the critical value. Moreover, the underidentification test is also passed at the 1% significance level. The second-stage results in Column (4) reveal a DRI coefficient of 5.614 that is statistically significant at the 1% level, which further confirms the promotional effect of DRI on GIP.

Synthesizing the results from both instrumental variable tests, the core findings of this study remain valid after controlling for potential endogeneity, providing further support for hypothesis H1.

Table 5 Endogeneity Test Results

Variables	(1)	(2)	(3)	(4)
	DRI	GIP	DRI	GIP
DRI		9.682*		5.614***
		(1.664)		(3.700)
rob	-0.001***			
	(-4.123)			
L.DRI			0.449***	
			(7.627)	
_cons	0.314***		0.051	
	(3.098)		(0.508)	
Control	Yes	Yes	Yes	Yes

City fixed	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes
N	1,155	1,155	1,050	1,050
F statistic	17.00		58.17	
Kleibergen-Paap rk LM statistic	18.139		81.071	
Kleibergen-Paap rk Wald F statistic	16.997		58.165	
* p < 0.1, ** p < 0.05, *** p < 0.01				

5.2 Analysis of Mediation Effect Test Results

Table 6 reports the test results for the mediation effects, where Column (1) presents the baseline regression results. Columns (2) to (3) investigate the mediating path through NQP. Column (2) reveals that the coefficient of DRI on NQP is 0.459, which is statistically significant at the 5% level. In Column (3), the coefficients of both DRI (2.063) and NQP (0.184) are statistically significant. This confirms that NQP plays a positive mediating role in the relationship between DRI and GIP. This mechanism is clearly reflected within the Yangtze River Economic Belt (YREB). The Yangtze River Delta region, by virtue of its robust digital industry clusters, is accelerating the formation of an NQP paradigm that integrates intelligent and green manufacturing. Meanwhile, the Chengdu-Chongqing Economic Zone leverages its big data advantages to promote the intelligent and low-carbon transformation of traditional industries. The inherent green orientation of this advanced form of productivity systematically channels innovation resources toward green and low-carbon sectors (Shi et al., 2023), thereby ultimately improving GIP output. Thus, Hypothesis 2 (H2) is confirmed.

Table 6 Mediation Effect Test Results

Variables	(1)	(2)	(3)
	GIP	NQP	GIP
DRI	2.148***	0.459**	2.063***
	(3.599)	(2.039)	(3.465)
NQP			0.184**
			(2.008)
RMI			
_cons	-3.154*	-0.254	-3.107*
	(-1.820)	(-0.419)	(-1.797)
Control	Yes	Yes	Yes
City fixed	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes
N	1155	1155	1155
R^2	0.973	0.551	0.973
* p < 0.1, ** p < 0.05, *** p < 0.01			

5.3 Analysis of Moderating Effect Test Results

Table 7 reports the test results for the moderating effects. As shown in Column (1) of Table 7, the results reveal that the coefficient of the interaction term (DRI×ENV) is 2.214, which is statistically significant. This confirms that within the strategic context of prioritizing ecological protection in the YREB, stringent environmental regulation (ENV) effectively channels the outcomes of DRI toward GIP-related fields. Thus, Hypothesis 3 (H3) is supported.

As indicated in Column (2) of Table 7, the coefficient of the interaction term (DRI×LGC) is 0.040, which is statistically significant, indicating that LGC exerts a positive moderating effect on the relationship between DRI and GIP. This finding implies that, under the guidance of the YREB development strategy, provincial and municipal governments along the river have introduced supportive policies and strived to establish regional models for the synergistic development of DRI and GIP. This benign competitive landscape significantly

enhances the innovation effectiveness of DRI. Thus, Hypothesis 4 (H4) is validated.

As demonstrated in Column (3) of Table 7, the coefficient of the interaction term (DRI×GDA) is -4.747, which is statistically significant, indicating that GDA plays a negative moderating role. This suggests that excessive government intervention in the DRI process may distort market signals via administrative intervention, thereby potentially suppressing firms' autonomous innovation vitality. The phenomenon of digital performance-oriented projects observed in some parts of the YREB partially supports this finding. Thus, Hypothesis 5 (H5) is confirmed.

Table 7 Moderating Effect Test Results

Variables	(1)	(2)	(3)
	GIP	GIP	GIP
DRI×ENV	2.214**		
	(1.968)		
DRI×LGC		0.040***	
		(5.450)	
DRI×GDA			-4.747***
			(-5.850)
Control	Yes	Yes	Yes
City fixed	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes
_cons	-3.328*	-3.418*	-3.322*
	(-1.938)	(-1.950)	(-1.923)
N	1155	1155	1155
R^2	0.973	0.973	0.974
* p < 0.1, ** p < 0.05, *** p < 0.01			

6. Heterogeneity analysis

6.1 Heterogeneity by Central City Status

Columns (1) and (2) present results classified by whether a city is designated as a central city, which are defined as provincial capitals, sub-provincial cities, or municipalities directly under the central government. In Column (2), the coefficient of DRI for non-central cities is 1.969 and statistically significant, a finding that challenges the conventional core-periphery theory. This finding highlights the inclusive and democratizing potentialities of digital technologies. Within the YREB, peripheral cities such as Yichang and Wuhu have successfully surmounted geographic and institutional disadvantages by virtue of their in-depth integration into the region's digital industrial corridor, thereby achieving remarkable progress in GIP. By comparison, core cities often face structural rigidities and entrenched innovation paths, which restrict the marginal returns of DRI.

6.2 Heterogeneity by Entrepreneurial Activity

Columns (3) and (4) investigate heterogeneity classified by local entrepreneurial dynamism. In Column (5) of Table 7, where entrepreneurial activity is relatively low—which is common in the middle and upper reaches of the Yangtze River—the coefficient of DRI is 2.661, which is statistically significant. This suggests that DRI compensates for deficits in physical entrepreneurial ecosystems by virtue of enabling virtual innovation platforms that lower entry barriers and facilitate cross-organizational collaboration. Such digital infrastructure provides novel organizational forms for green technological breakthroughs (Nambisan, 2017). By contrast, in regions with high entrepreneurial activity, problems such as scattered and fragmented innovation resources and redundant competition may attenuate the marginal impact of DRI.

Table 8 Heterogeneity Analysis Results

Variables	(1)	(2)	(3)	(4)
	Central Cities	Non-central Cities	High Entrepreneurial Activity	Low Entrepreneurial Activity
	GIP	GIP	GIP	GIP

DRI	0.949	1.969**	-0.217	2.661***
	(1.294)	(2.543)	(-0.322)	(2.722)
Control	Yes	Yes	Yes	Yes
City fixed	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes
_cons	-6.615	-5.630***	6.224*	-6.077**
	(-1.322)	(-2.867)	(1.808)	(-2.053)
N	132	1023	411	723
R^2	0.979	0.962	0.987	0.960
* p < 0.1, ** p < 0.05, *** p < 0.01				

7. Discussion

7.1 Research Conclusions

Using panel data from 105 prefecture-level cities in the Yangtze River Economic Belt (YREB) spanning 2011 to 2021, this study systematically explores the mechanisms through which DRI influences GIP. The main findings are summarized as follows. First, quantitative analysis indicates that DRI in the YREB has entered an intermediate stage of development and maintains a positive growth trend, yet there remains considerable potential for further improvement in the overall integration level. Notable regional disparities exist, with the integration level showing a gradual decreasing trend from the downstream to the midstream and upstream regions. Second, empirical results confirm that DRI significantly promotes GIP, a conclusion that remains valid after addressing endogeneity concerns and conducting a series of robustness tests. Mechanism analysis shows that new quality productive forces (NQP) play a positive mediating role between DRI and GIP. Moderating effect analysis indicates that both environmental regulation (ENR) and local government competition (LGC) enhance the positive impact of DRI on GIP. In contrast, government digital attention (GDA) exerts a significant negative moderating effect, indicating that excessive administrative intervention may dampen the GIP vitality of market entities. Furthermore, heterogeneity analysis shows that the promotional effect of DRI on GIP is more pronounced in non-central cities and regions with low entrepreneurial dynamism. This highlights its unique value in advancing regional coordination and mitigating green development imbalances.

7.2 Policy Implications

Drawing on our findings—including that DRI promotes GIP through two key channels: (i) enhancing new quality productive forces (NQP) and (ii) mitigating resource misallocation that environmental regulation (ENR) and local government competition (LGC) enhance this promotional effect while excessive government digital attention (GDA) may weaken it, and that the impacts of DRI on GIP vary across the upper, middle, and lower reaches of the Yangtze River Economic Belt (YREB) as well as across different city types, we propose the following region-differentiated and instrument-targeted policy implications.

7.2.1 A tiered DRI implementation roadmap: Downstream “ In-Depth Application ”, Midstream “ Systematic Upgrading ”, and Upstream “ Capacity Building ”

Downstream (Yangtze River Delta): The focus should shift from infrastructure expansion to scenario-driven adoption and standards-based governance. Leveraging chain-leading firms and industrial parks, efforts should be made to scale up industrial internet platforms and digital twin applications in fields such as green manufacturing, energy management, and low-carbon logistics. Meanwhile, compliant data circulation mechanisms and green data standards (e.g., carbon accounting protocols and product carbon footprint data interfaces) should be developed to disseminate replicable solutions to upstream and midstream regions.

Instruments: Scenario-based pilots (mission-oriented programs), industry standards and interface specifications, green procurement policies and “first-of-its-kind” supportive measures, as well as park-level DRI demonstration evaluation and assessment, should be promoted to advance the in-depth application of DRI in the downstream region.

Midstream (Mid-Yangtze): Priority should be given to the integration of digital retrofitting of manufacturing and green process upgrading. An integrated scheme combining digital transformation vouchers for small and medium-sized enterprises (SMEs) and interest subsidies for green upgrading should be established to encourage the retrofitting of smart energy-saving equipment, online energy monitoring, and the upgrading of process control systems.

Instruments: Transformation vouchers, interest subsidies, energy performance contracting (EPC) coupled with digital monitoring, and standardized diagnostic service packages.
Upstream (Chengdu–Chongqing and upper reaches): The primary focus should be on filling the gaps in industrial-side foundational capabilities, such as industrial internet access, computing and edge nodes, as well as sensing and data collection systems. Efforts should start with modular, low-cost, and replicable retrofitting initiatives, while avoiding " one-size-fits-all" large-scale projects.
Instruments: Regional industrial internet public service platforms, "rent instead of build" for computing/edge capacity, park-level unified low-cost SaaS deployment, phased acceptance linked to energy-intensity reduction and green patent outputs.

7.2.2 Operationalize the "NQP–green innovation" linkage via an industry–technology–talent–finance policy package
Given that NQP is a key transmission channel, policies should translate NQPF cultivation into actionable packages.
Downstream: promote joint "digital + green" breakthroughs in smart manufacturing, clean-energy equipment, low-carbon materials, and green supply-chain software, with incentives tilted toward high-quality green invention patents and standards.
Instruments: mission-oriented R&D programs, firm-led university–industry consortia, rewards based on patent quality (e.g., invention patents/highly cited patents).
Midstream: support upgrading in incumbent industries (steel, chemicals, building materials, automotive) through green process packages and industrial software substitution to create scalable technical roadmaps.
Instruments: common-technology platforms, catalogues of green process packages, combined subsidies and super deductions for software substitution and green upgrading.
Upstream: emphasize application-oriented innovation and engineering deployment to lower trial-and-error costs for green technologies.
Instruments: first-batch application subsidies, demonstration insurance/compensation, "engineer-in-factory + digital diagnosis" services for SMEs.

7.2.3 Improve environmental regulation and government competition: compete on green outcomes, not digital metrics, and reduce administrative crowding-out
Performance metric redesign: bind DRI performance with green innovation outcomes and reduce competition over simple digital-project counts. Include indicators such as green patent quality, carbon intensity reduction, and green TFP improvements, with differentiated weights across upper–middle–lower reaches.
From picking technologies to setting rules and incentives: rely more on standards, market mechanisms, and outcome-based subsidies, avoiding direct administrative intervention in firms' technology pathways and preventing "digital vanity projects" from crowding out market-driven innovation.
Instruments: pay-for-performance, ex-post subsidies, third-party verification and standards, negative-list governance.

7.3 Limitations and Future Research
While this study has adopted multiple methods to ensure the robustness of its conclusions, several limitations persist, which also point to directions for future research.
First, in the moderating effect analysis, there may be a potential bidirectional causal relationship between Government Digital Attention (GDA) and green innovation. For instance, regions with active green innovation activities may naturally attach greater importance to digital topics. This demand-induced endogeneity may compromise the precise estimation of the moderating effect. Although this study provides robust theoretical reasoning and its core findings remain consistent across multiple model specifications, future research could more rigorously identify the net moderating effect of GDA by adopting more exogenous instrumental variables (e.g., the promotion intensity of higher-level digital policies) or quasi-experimental designs.
Second, the mechanism tests are of an indirect nature. While this study provides robust statistical evidence for the theoretical mechanisms via mediation effect models (i.e., enhancing New Quality Productive Forces, NQP), these tests remain indirect validations relying on city-level macro data. Future research integrating firm-level micro-data, policy text analysis, or case studies could more directly uncover the micro-causal chain between technological penetration, organizational change, and green innovation behavior during the DRI process.

Finally, the findings are limited by their external validity and failure to capture dynamic characteristics. This study focuses on the Yangtze River Economic Belt (YREB), a specific national strategic region. Its conclusions are informative for similar river basin economies worldwide at comparable development stages and under similar policy contexts, but caution is warranted when generalizing to other institutional and cultural settings. Moreover, both DRI and green innovation are dynamically evolving processes. The cross-sectional observations based on data spanning 2011 to 2021 in this study fail to fully capture the long-term nonlinear relationships between them and their stage-specific characteristics. Future studies could extend the observation period or adopt models capable of capturing dynamic interactions, such as the Panel Vector Autoregression (PVAR) model, for supplementary analysis.

Ethics approval and consent to participate

Ethics approval was not applicable. This study did not involve any human participants or animal subjects.

Data availability statement

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

First, Chongqing Municipal Social Science Planning Program: Research on the Mechanism of AI-Driven Co-Benefits of Pollution and Carbon Reduction in the Chengdu-Chongqing Economic Circle (2025ZXYB39).

Second, Project of Humanities and Social Sciences Research Base of Chongqing Municipal Education Commission: Research on the Pathways for Advanced Manufacturing Clusters to Promote Resilience Governance in Chongqing Megacity (25SKJD227).

Third, Chongqing Education Science Planning Project (Youth Project, 2025): Research on the Collaborative Governance of Industry-Education Integration in Application-Oriented Undergraduate Universities under Digital-Intelligent Transformation (K25YY2210049).

List of Abbreviations

Abbreviation	Definition
DRI	Digital-Real Integration
GIP	Green Innovation
YREB	Yangtze River Economic Belt
NQP	New Quality Productive Forces
ENR	Environmental Regulation
LGC	Local Government Competition
GDA	Government Digital Attention

References

Huang, J.-W., & Li, Y.-H. (2017). Green innovation and performance: The view of organizational capability and social reciprocity. *Journal of Business Ethics*, *145*(2), 309–324. https://doi.org/10.1007/s10551-015-2903-y

Lin, R.-J.,Tan, K.-H.,& Geng,Y.(2013).Market demand, green product innovation, and firm performance: Evidence from Vietnam motorcycle industry.*Journal of Cleaner Production*,*40*,101–107. https://doi.org/10.1016/j.jclepro.2012.11.033

Ahmed, R. R., Akbar, W., Aijaz, M., Channar, Z. A., Ahmed, F., & Parmar, V. (2023). The role of green innovation on environmental and organizational performance: Moderation of human resource practices and management commitment. *Heliyon*, *9*(1), e12679. https://doi.org/10.1016/j.heliyon.2022.e12679

Cheng,C.C.J.(2020).Sustainability orientation, green supplier involvement,and green innovation performance: Evidence from diversifying green entrants. *Journal of Business Ethics*,*161*(2),393–414. https://doi.org/10.1007/s10551-018-3946-7

Sun, G., Fang, J., Li, J., & Wang, X. (2024). Research on the impact of the integration of digital economy and real economy on enterprise green innovation. Technological Forecasting and Social Change, 200, 123097. https://doi.org/10.1016/j.techfore.2023.123097

Du, S., & Cao, J. (2023). Non-family shareholder governance and green innovation of family firms: A socioemotional wealth theory perspective. International Review of Financial Analysis, 90, 102857. https://doi.org/10.1016/j.irfa.2023.102857

Luo, K., Liu, Y., Chen, P.-F., & Zeng, M. (2022). Assessing the impact of digital economy on green development efficiency in the Yangtze River Economic Belt. Energy Economics, 112, 106127. https://doi.org/10.1016/j.eneco.2022.106127

Meng, X.-N. (2023). Can digital-real integration promote industrial green transformation: Fresh evidence from China's industrial sector. *Journal of Cleaner Production*, 426, 139116. https://doi.org/10.1016/j.jclepro.2023.139116

Liu, B., Huang, Y., Chen, M., & Lan, Z. (2024). Towards sustainability: How does the digital-real integration affect regional green development efficiency? *Economic Analysis and Policy*, 83, 42–59. https://doi.org/10.1016/j.eap.2024.06.008

Teece, D. J. (2018). Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. *Research Policy*, 47(8), 1367–1387. https://doi.org/10.1016/j.respol.2017.01.015

Ghobakhloo,M. (2020).Industry 4.0,digitization, and opportunities for sustainability.*Journal of Cleaner Production*,*252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Sun, G., Yin, D., Kong, T., & Yin, L. (2024). The impact of the integration of the digital economy and the real economy on the risk of stock price collapse. *Pacific-Basin Finance Journal*, 85, 102373. https://doi.org/10.1016/j.pacfin.2024.102373

Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of Economic Literature*, 57(1), 3–43. https://doi.org/10.1257/jel.20171452

Zhang, C., Liu, B., & Yang, Y. (2024). Digital economy and urban innovation level: A quasi-natural experiment from the strategy of "Digital China." *Humanities and Social Sciences Communications*, *11*(1), 574. https://doi.org/10.1057/s41599-024-03122-1

Feng, G.-F., Jiang, P.-C., Yin, Z., & Chang, C.-P. (2025). Bytes drive green: Decoding the global digital economy's environmental impact. *Stochastic Environmental Research and Risk Assessment*. https://doi.org/10.1007/s00477-024-02680-3

Chong,Y,Zhang,Y.,Di,D,Chen,Y,&Wang,S(2024).Digital transformation and synergistic reduction in pollution and carbon emissions—An analysis from a dynamic capability perspective. *Environmental Research*, *261*,119683. https://doi.org/10.1016/j.envres.2024.119683

Yu, Z., Liu, Y., Yan, T., & Zhang, M. (2024). Carbon emission efficiency in the age of digital economy: New insights on green technology progress and industrial structure distortion. *Business Strategy and the Environment*, *33*(6), 4039–4057. https://doi.org/10.1002/bse.3683

Zhang, Y., Sun, M., Yang, R., Li, X., Zhang, L., & Li, M. (2021). Decoupling water environment pressures from economic growth in the Yangtze River Economic Belt, China. *Ecological Indicators*, *122*, 107314. https://doi.org/10.1016/j.ecolind.2020.107314

Yoffie, D. B. (1996). Competing in the age of digital convergence. *California Management Review*, *38*(4), 31–53.

Curran,C.S,Bröring,S,&Leker,J(2010).Anticipating converging industries using publicly available *data.Technological Forecasting and Social Change,77(3),385–395.* https://doi.org/10.1016/j.techfore.2009.10.002

Hojeghan, S. B., & Esfangareh, A. N. (2011). Digital economy and tourism impacts, influences and challenges. *Procedia-Social and Behavioral Sciences*, *19*, 308–316. https://doi.org/10.1016/j.sbspro.2011.05.136

Cheng, L., & Zhou, Y. (2023). Can "digital-real integration" enable the innovation output of agricultural enterprises? An analysis based on the moderating role of financial flexibility. *Technology Analysis & Strategic Management*, 1–15. https://doi.org/10.1080/09537325.2023.2293849

Hong, Y. X., & Ren, B. P. (2023). Connotation and approach of deep integration of the digital economy and the real economy. *China Industrial Economics*, (2), 5–16.

Xin, Y., Song, H., Shen, Z., & Wang, J. (2023). Measurement of the integration level between the digital economy and industry and its impact on energy consumption. *Energy Economics*, *126*, 106988. https://doi.org/10.1016/j.eneco.2023.106988

Gambardella, A., & Torrisi, S. (1998). Does technological convergence imply convergence in markets? Evidence from the electronics industry. *Research Policy*, 27(4), 445–463. https://doi.org/10.1016/S0048-7333(98)00062-6

Fai, F., & von Tunzelmann, N. (2001). Industry-specific competencies and converging technological systems: Evidence from patents. *Structural Change and Economic Dynamics*, *12*(2), 141–170. https://doi.org/10.1016/S0954349X(00)00035-7

Guerrieri, P., & Meliciani, V. (2004). International competitiveness in producer services. SSRN. https://doi.org/10.2139/ssrn.521445

Chen, Y.-S., Lai, S.-B., & Wen, C.-T. (2006). The influence of green innovation performance on corporate advantage in Taiwan. *Journal of Business Ethics*, *67*(4), 331–339. https://doi.org/10.1007/s10551-006-9025-5

Saunila, M., Ukko, J., & Rantala, T. (2018). Sustainability as a driver of green innovation investment and exploitation. *Journal of Cleaner Production*, *179*, 631–641. https://doi.org/10.1016/j.jclepro.2017.11.211

Hojnik, J., & Ruzzier, M. (2016). What drives eco-innovation? A review of an emerging literature. *Environmental Innovation and Societal Transitions*, *19*, 31–41. https://doi.org/10.1016/j.eist.2015.09.006

Huang, J., Zhou, L., Song, S., & Zhou, H. (2025). The impact of defamilization on green innovation: Evidence from SRDI family firms in China. *PLOS ONE*, *20*(1), e0314110. https://doi.org/10.1371/journal.pone.0314110

Wagner, M. (2007). On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Research Policy*, *36*(10), 1587–1602. https://doi.org/10.1016/j.respol.2

007.08.004

Li, D., Zheng, M., Cao, C., Chen, X., Ren, S., & Huang, M. (2017). The impact of legitimacy pressure and corporate profitability on green innovation: Evidence from China top 100. *Journal of Cleaner Production*, *141*, 41–49. https://doi.org/10.1016/j.jclepro.2016.08.123

Zhang, C., Zhou, B., & Tian, X. (2022). Political connections and green innovation: The role of a corporate entrepreneurship strategy in state-owned enterprises. *Journal of Business Research*, *146*, 375–384. https://doi.org/10.1016/j.jbusres.2022.03.084

Kong, T., Sun, R., Sun, G., & Song, Y. (2022). Effects of digital finance on green innovation considering information asymmetry: An empirical study based on Chinese listed firms. *Emerging Markets Finance and Trade*, *58*(15), 4399–4411. https://doi.org/10.1080/1540496X.2022.2083953

Maestre-Andrés, S., Drews, S., Savin, I., & van den Bergh, J. (2021). Carbon tax acceptability with information provision and mixed revenue uses. *Nature Communications*, *12*(1),7017. https://doi.org/10.1038/s41467-021-27380-8

Ahmad, B., Shafique, I., Qammar, A., Ercek, M., & Kalyar, M. N. (2024). Prompting green product and process innovation: Examining the effects of green transformational leadership and dynamic capabilities. *Technology Analysis & Strategic Management*, *36*(9), 1111–1123. https://doi.org/10.1080/09537325.2022.2071692

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance. *International Journal of Production Economics*, *239*, 108205. https://doi.org/10.1016/j.ijpe.2021.108205

Sun, H., Tang, C., Gao, P., & Zhou, G. (2025). Digital economy, energy consumption and urban carbon emission reduction: Empirical evidence from 278 cities in China. *Sustainable Futures*, *10*, 100858. https://doi.org/10.1016/j.sftr.2025.100858

Danish,& Ulucak, R. (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. *Science of The Total Environment*, *712*, 136504. https://doi.org/10.1016/j.scitotenv.2020.136504

Lange,S.,Pohl,J.,&Santarius,T.(2020).Digitalization and energy consumption.Does ICT reduce energy demand?*Ecological Economics*,*176*,106760. https://doi.org/10.1016/j.ecolecon.2020.106760

Huang, T., & Xia, H. (2024). How can digital–real economy integration affect urban green innovation? Evidence from China. *Sustainability*, *16*(24), 11072. https://doi.org/10.3390/su162411072

Li, H., Liu, Z., & Hachard, V. (2024). Digital transformation driving green innovation: Evidence from Chinese A-share firms. *International Review of Economics and Finance*, *95*, 103487. https://doi.org/10.1016/j.iref.2024.103487

Wang,Y.,Shi,M.,Liu,J.,Zhong, M., & Ran,R.(2025). The impact of digital-real integration on energy productivity under a multi-governance framework:The mediating role of AI and embodied technological progress.*Energy Economics*,*142*,108167. https://doi.org/10.1016/j.eneco.2024.108167

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, *102*(1), 131–166. https://doi.org/10.1257/aer.102.1.131

Brynjolfsson, E., & Hitt, L. M. (2000). Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives*, *14*(4), 23–48. https://doi.org/10.1257/jep.14.4.23

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5), S71–S102. https://doi.org/10.1086/261725

Coase, R. H. (2013). The problem of social cost. *Journal of Law and Economics*, *56*(4), 837–877. https://doi.org/10.1086/674872

Williamson,O.E(1988).Corporate finance and corporate governance.*The Journal of Finance*,*43*(3),567–591.https://doi.org/10.1111/j.15406261.1988.tb04592.x

Zhang,Z,Li,P.,Wang,X.,Ran,R.,&Wu,W(2024).New energy policy and new quality productive forces:A quasi-natural experiment based on demonstration cities. *Economic Analysis and Policy*,*84*,1670–1688. https://doi.org/10.1016/j.eap.2024.10.039

Zhang, J., Shan, Y., Jiang, S., Xin, B., Miao, Y., & Zhang, Y. (2024). Study on the coordinated development degree of new quality productivity and manufacturing carbon emission efficiency in provincial regions of China. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-05321-x

Liu, Y., & He, Z. (2024). Synergistic industrial agglomeration, new quality productive forces and high-quality development of the manufacturing industry. *International Review of Economics and Finance*, *94*, 103373. https://doi.org/10.1016/j.iref.2024.103373

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, *9*(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Yu, H., Wang, J., Hou, J., Yu, B., & Pan, Y. (2023). The effect of economic growth pressure on green technology innovation: Do environmental regulation, government support, and financial development matter? *Journal of Environmental Management*, *330*, 117172. https://doi.org/10.1016/j.jenvman.2022.117172

Hao,Z. (2024). Does market competition mechanism promote enterprise digital transformation?A quasi-natural experiment based on the negative list system of market access. *Foreign Economics & Management*,*46*(2),136–152. https://doi.org/10.16538/j.cnki.fem.20220811.402

Wu,J.,&Wang,B(2022). Environmental competition, environmental attention, and environmental governance efficiency of local governments: An empirical study based on the panel data of prefecture-level cities. *Journal of Northeastern University (Social Science)*, *24*(6), 33–40. https://doi.org/10.15936/j.cnki.1008-3758.2022.06.005

Ma,Y.,Chen,X.,Lei,X.,&Zhang,C(2025). The impact of local government competition on green total factor productivity:Economic- environmental comprehensive competition and transformation effects. *Journal of Natural Resources*, *40*(2), 459–477. https://doi.org/10.31497/zrzyxb.20250211

Jones, B. D., Baumgartner, F. R., & Talbert, J. C. (1993). The destruction of issue monopolies in congress. *American Political Science Review*, *87*(3), 657–671. https://doi.org/10.2307/2938742

Guo, L., & Jiang, X. (2022). Decentralization of environmental management and enterprises' environmental technology innovation: Evidence from China. *Applied Economics*,*54*(36),4170–4186. https://doi.org/10.1080/00036846.2021.1942648

Yue,L,&Han,L(2025).The digital empowerment promotes synergistic efficiency in regional pollution reduction and carbon emission reduction—Analysis of the moderating effects of market structure and government behavior.*Journal of Cleaner Production*, *493*,144867.https://doi.org/10.1016/j.jclepro.2025.144867

Ocasio,W (1997).Towards an attention- based view of the firm. *Strategic Management Journal*, *18*(S2), 187–206.https://doi.org/10.1002/(SICI)1097-0266(199708)18:2+<187::AID-SMJ884>3.0.CO;2-Z

Zhang,Z.,Luo,X.,Du,J.,& Xu, B. (2024). Substantive or strategic: Government R&D subsidies and green innovation. *Finance Research Letters*, *67*, 105796. https://doi.org/10.1016/j.frl.2024.105796

Gulen, H., & Ion, M. (2016). Policy uncertainty and corporate investment. *The Review of Financial Studies*, *29*(3), 523–564. https://doi.org/10.1093/rfs/hhv050

Wang, M.,Wurgler,J.,&Zhang,H.(2026).Policy uncertainty reduces green innovation.*Journal of Financial Economics*, *175*,104189. https://doi.org/10.1016/j.jfineco.2025.104189

Baker,S.R.,Bloom,N.,&Davis,S.J.(2016). Measuring economic policy uncertainty. *Quarterly Journal of Economics*, *131*(4),1593–1636. https://doi.org/10.1093/qje/qjw024

Tao, Z., Zhang, Z., & Shangkun, L. (2022). Digital economy, entrepreneurship, and high- quality economic development: Empirical evidence from urban China. *Frontiers of Economics in China*, *17*(3), 393–418. https://doi.org/10.1007/s11459-022-01210-9

Xu, Z., Xu, W., & Xin, D. (2025). Digital–real economy integration and urban low-carbon development in China. *Economic Analysis and Policy*, 86, 606-621.

Wang,H.,Gong,K.,Du,F.,&Sun,W.(2024).Does the low- carbon city pilot policy achieve the synergistic effect of pollution and carbon reduction?*Energy & Environment*, *35*(3),569–596. https://doi.org/10.1177/0958305X231218202

Zhou, W., & Xu, L. (2023). On new quality productivity: Connotative characteristics and important focus. *Reform*, (10), 1–13.

Chen, S. Y., & Chen, D. K. (2018). Air pollution, government regulations and high- quality economic development. *Economic Research Journal*, *53*(11), 20–34.

Meng, X., Kong, F., Fu, H., Li, S., & Zhang, K. (2024). Is more always better? How government ecological attention influences corporate environmental responsibility: Empirical evidence from Chinese listed companies. *Ecological Indicators*, *159*, 111686. https://doi.org/10.1016/j.ecolind.2024.111686

Peng,Z.,Huang,Y.,Liu,L.,Xu,W.,&Qian,X(2024).How government digital attention alleviates enterprise financing constraints:An enterprise digitalization perspective.*Finance Research Letters*,*67*,105883. https://doi.org/10.1016/j.frl.2024.105883

Xu, W., Peng, Z., Feng, Z., & Peng, C. (2025). The impact of government digital attention on enterprise digital transformation: Empirical insights from China. *Applied Economics Letters*, *32*(17), 2713–2718. https://doi.org/10.1080/13504851.2024.2339370

Huo, X., & Dong, Y. (2025). From market segmentation to consumption growth: How does digital- real integration strengthen the consumption stimulation effect in a unified national market? *International Review of Economics and Finance*, *103*, 104497. https://doi.org/10.1016/j.iref.2025.104497

To cite this article: Hadi Santoso*, Jimmy Tje. (2026). *Regression Tree-Based Segmentation of Enterprise Value: Bridging Machine Learning and Classical Financial Analysis, Journal of Financial and Economic Dynamics*, 1,(1), 21-31;https://doi.org/10.66361/jfed.47

Regression Tree-Based Segmentation of Enterprise Value: Bridging Machine Learning and Classical Financial Analysis

Hadi Santoso[1], Jimmy Tjen[2]*
[1] Department of Management, Faculty of Economics and Business, Universitas Widya Dharma Pontianak, Indonesia, Jalan Gajah Mada No. 49, Pontianak, West Kalimantan,
[2] Department of Informatics, Faculty of Information Technology, Universitas Widya Dharma Pontianak, Jalan Gajah Mada No. 49, Pontianak, West Kalimantan, Indonesia, jimmy.tjen@mathmods.eu
**Corresponding author: Hadi Santoso, hadisantoso@widyadharma.ac.id*

Abstract: In this study, a novel hybrid analytical framework between the regression tree (RT) from machine learning and classical econometrics analysis is presented to understand the relationship between financial parameters and enterprise value (EV). Five predictors, which are: return on equity (ROE), debt-to-asset ratio (DAR), institutional ownership (IO), firm size, and firm age, were examined as independent variables. In particular, the algorithm was applied to split a dataset of 52 Indonesian consumer sector firms, dated from 2018 to 2023, where a linear regression model was assigned to each cluster of data. Based on the conducted numerical simulations, it was concluded that ROE and firm size had a consistently positive effect on the EV across all clusters. Meanwhile, the effect of IO, DAR, and age varied on each node. These findings suggest that the relation between financial parameters and firm value (FV) is not uniform and can be interpreted better by considering multi-segment data. This method serves as a new data-driven methodology to the traditional panel analysis, which is complex and requires significant knowledge in analytical statistics.
Keywords: Enterprise value, Firm value, Firm size, Machine learning, Regression tree

1.Introduction

Firm value (FV) is considered the expectation of investors toward a firm, which is materialized in the form of stock prices. FV is the current profit of all shareholders to be obtained in the future. Investors, in particular, before deciding to invest in a firm, will try to analyze the firm's performance. This performance is reflected in the capability of that firm to gain a return on equity (ROE), the capability of the firm to manage resources, and the implementation of good corporate governance (GCG). Furthermore, this value also depends on the firm's size and the length of time the firm has been operating.

The influence of profitability, capital structure, firm size, and firm age on the firm value has been presented in numerous works, for example, in the research conducted by Susanti & Restiana (2018) and Lubis et al. (2017). A paper by Bhullar (2017) showed that profitability is negatively correlated with the enterprise value (EV) of pharmaceutical companies.

Research by

An et al. (2017) demonstrated that the EV can properly explain firm value by considering not only the capital market but also the duties that need to be paid.

Another research that aimed to study the influence of capital structure on FV was conducted by Saputra & Fachrurrozie (2015a), where they found that the capital structure correlated negatively with the FV. Meanwhile, research conducted by Asif and Aziz (2016), Hirdinis (2019), Yundari and Sedana (2020), Bui (2023), and Irawan (2022) showed that the capital structure correlated positively with the FV.

The authors: Jhang et al. (2020) , Lestari (2017), and Salehi (2022) have studied the influence of institutional ownership (IO) on FV. They have found that the IO correlated positively with the FV.
Another research conducted by Jhang et al. (2020) showed that equity ownership correlated negatively with the FV.
On the contrary, the research done by Wu (2022) showed that while the IO affects the FV, ownership concentration does not affect this parameter.
In Saputra and Fachrurrozie (2015), research was conducted to understand the effect of firm size on FV. In their paper, it is shown that the firm size does not affect the FV.
However, in the research conducted by Susanti and Restiana (2018), it was shown that the firm size correlated negatively with the EV, while Lambey (2021) showed the opposite effect, instead.
Research to study the effect of firm age on the FV was performed by Lambey (2021), who showed that firm age does not affect the FV. On the contrary, the research conducted by Susanti and Restiana (2018) and Satrio (2022) showed that this variable correlated positively with the FV.

2.Contributions.

This study aimed to study the influence of capital structure, profitability, IO, firm size, and age on the FV, which is represented by the EV, by leveraging the regression tree (RT) model from the field of machine learning. The RT algorithm is an algorithm which is able to split the data into several segments by minimizing the variance of the dataset. In this way, similar samples are concentrated inside a specific node, where later a linear model can be fitted into it, to understand the dynamics of the variable for that node. This idea was first presented by Hadi Santoso in 2024 to study how parameters behave at certain value ranges. By combining the concept of machine learning and the classical econometrics approaches, it is possible to better exploit how the dependent variables affect EV at different levels.
In this study, the ROE is used as an indicator to measure profitability, while the debt-to-assets ratio (DAR) represents the capital structure. The IO is defined as the ratio of shares owned by institutional investors to the total number of available shares. The firm size is measured by total assets, while the firm age is defined as the number of years that have passed since the initial public offering (IPO) up to the time of this research. We then divide the data into several segments by using the RT model, and then study how those variables affected the EV on certain values. Details of this process will be discussed in Section III.
This paper consists of five sections: the first section is the introduction. In Section 2, we present the theoretical background that supported this study. The third section will discuss the research methodology, including how the RT model is generated from the dataset. The fourth section will present the results and findings based on the conducted numerical simulation. Finally, in the last section, we conclude the results presented in this paper.

3. Theoretical Review

According to Ben (2026), FV can be used to represent assets owned by a firm, including marketable securities. Investors, in particular, expect higher returns on investment or at least returns that remain the same relative to the risk gained, based on the time value of money of their investment (Djaja, 2017: 3). The dynamics of stock prices depend on the performance of the firm. Specifically, a firm with good performance tends to attract more investors to invest in it, which ultimately raises the FV. This value can be measured from 2 different perspectives: internal and external. From the internal perspective, FV can be measured by considering the performance of a firm in generating net profit for investors, i.e., in the form of ROE (Anita, 2023). From the external perspective, the FV can be observed through the capital price of that firm, such as by observing the expectations of investors on the share price. In particular, this shows that FV can be measured by several parameters, such as price-earnings ratio (PER), earnings per share (EPS), market-to-book ratio, and market capitalization (Ross et al., 2015: 53-54), and EV (Ross et al., 2022).
The firm's business operational activity is one of the firm's management duties in managing funding activities. During this process, management needs to observe and ensure that all regulations related to generating net profit are run optimally. In particular, the net gain is considered to be optimal if the management can utilize every resource and able to manage assets properly. These regulations include:

production, cost, promotion, human resources, and distribution. Specifically, an increase in profit margin can be used as an indicator of effective and efficient business operation regulation.

A firm with a high net profit margin demonstrates the firm's efficiency in managing assets and available funds, which is reflected through a high ROE (Mareta, 2022). A firm with a high ROE shows that it can manage its equity properly, which is often considered attractive to investors. In particular, when investors place greater trust in a firm, it is expected that that firm will have better prospects in the future. In particular, this claim is supported by several studies, such as those conducted by Susanti and Restiana (2018), Lubis et al (2017), and Ummah and Yuliana (2023), which showed that ROE correlates positively with the FV. Thus, based on the above explanation, we propose the following hypothesis:

H_1: ROE correlates positively with the EV.

A firm's funding decisions shape its capital structure. These decisions are closely related to the firm's life cycle, in addition to its overall size. Private companies, in particular, tend to rely more heavily on internal funding to support their operations, as obtaining external funding is generally more challenging and carries the risk of losing control of the firm (Damodaran, 2014:295). However, internal funding also comes with its limitations, such as capital loss that must be calculated using the risk and return model.

Debt levels are an important consideration for investors because they relate directly to the firm's obligation to third parties and the accompanying interest costs. A firm with high debt levels indicates a continued dependence on external borrowing. According to Brigham and Houston (2021:504), dependency on debt is perceived to be a negative trait by investors, which decreases the FV. This is because high levels of debt increase the risk of bankruptcy, especially when the firm encounters financial issues.

On the other hand, companies with strong growth and good performance may choose to utilize debt to fund their expansion, given that the cost of debt is typically lower than the cost of issuing new equity. In this case, the investors might consider this choice as a positive choice, which will increase the FV. In particular, several research has shown this interesting result, including Hirdinis (2019), Asif and Aziz (2016), Yundari and Sedana (2020), Bui (2023), and Irawan (2022), who have shown that capital structure has a positive effect on FV. Based on this explanation, we considered the following hypothesis:

H_2: DAR correlates positively with EV

GCG is essential to prevent conflicts of interest between managers who are entrusted with the authority and responsibility to manage the firm. Jerab (2023) stated that GCG reflects the structures and processes within and around an organization that allocate power and control over resources among participants. The implementation of GCG promotes better supervision of management performance through greater information transparency. In particular, this transparency helps the management to demonstrate greater caution when managing the firm, where every policy needs to be accountable.

Maulana et al. (2002) used the IO as a proxy to measure the effectiveness of GCG. IO refers to the shareholding of the firm by major financial institutions such as insurance companies, banks, and other investment firms. Wu (2022) claimed that institutional shareholders can help minimize agency conflicts between managers and shareholders, which in turn will improve the firm's performance and value.

On the contrary, the research conducted by Jhang et al. (2020), Lestari (2017), and Ferriswara (2022) showed the opposite effect, where IO correlates negatively with the FV.

Thus, by observing this information, we proposed the following hypothesis:

H_3: IO correlates positively with EV

Firm size denotes the size of a business entity based on the investor's perspective. Sui (2024) stated that the size of a firm reflects the magnitude of its operations. The larger the business, the greater the ability to generate FV. According to Ahmed (2023), firm size can be measured using several parameters, such as total assets. In particular, investors see large companies as a positive signal and prefer to invest in them, rather than in small companies. Thus, it is hinted that the firm size might affect the FV. This claim was further verified by the research conducted by Sui (2024) and Lambey (2021), who showed that the firm size correlates positively with the FV.

Thus, in this research, we also considered the following hypothesis:

H_4: Firm size correlates positively with the EV

Firm age denotes how long a firm has been operating. Companies that have been operating for a long time are often seen as more established and capable of overcoming various business-related problems. Susanti and Restiana (2018) stated that the more mature a firm is, the more information available for investors. In particular, this information can then be used to judge the performance of the firm, which in turn increases the trust placed by investors in it. According to Rujin and Sukirman (2020), firm age also determines the level of risk faced. Specifically, they stated that younger companies are much more prone to uncertainty and competition due to their lack of experience. Therefore, it can be seen that the firm's age might affect the FV due to how investors perceive the firm's capability to handle business-related problems. Research conducted by Susanti and Restiana (2018) and Satrio (2022) confirmed this, in which they stated that firm age positively correlates with FV.

Based on the explanation above, the hypothesis proposed in this study is:

H_5: Firm age correlates positively with EV

4. Research Methodology

This research is associative research, in which we considered a secondary dataset obtained from the Indonesian stock exchange (ind: Bursa Efek Indonesia). In particular, we collected data from 125 primary consumer sector companies from 2018 to 2023. The samples were collected by using the purposive sampling method, in which we selected companies that have been listed since 2017 and have never been suspended. Thus, eliminating 73 companies, leaving only 52 companies with 312 samples. The data was processed with MATLAB online, which is a semi-open programming language that is available without installation (registration is required for free 20 hours of access to the program).

This study aims to understand how the ROE, DAR, IO, firm size, and firm age affect FV, in this case represented by EV at a certain value. To reach this goal, first, the outliers are removed from the data. Then, the data is split into several segments by leveraging the RT algorithm based on a certain splitting criterion obtained from the independent variables. This partition ensures that every sample contained in any leaf is unique; it means that no two different leaves may have the same sample contained in them.

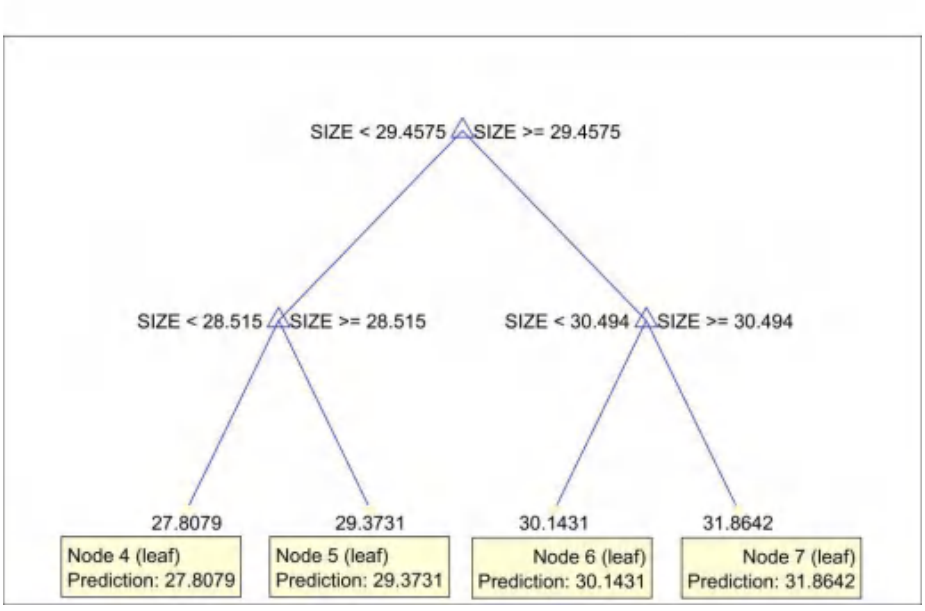


Figure 1 The tree graph representation of the data. The value located in each node (e.g., 27.80 in node 4) denotes the average of the EV contained in that node

Let l=1,2,…n denotes the number of leaves for the RT model, τ. Then, for each leaf, it is possible to assign a linear model, as denoted in equation 1.

$$EV(x_i)=\alpha_i ROE(x_i)+\beta_i DAR(x_i)+\gamma_i IO(xi)+\delta_i F_S(x_i)+\epsilon_i F_a(x_i)+c_i+\varepsilon_i \quad (1)$$

Where: $EV(x_i)$,$DAR(x_i)$, $IO(x_i)$, $F_S(x_i)$, $F_a(x_i)$, $\epsilon(i)$ and c_i denote the EV, DAR, IO, the firm size, the firm age, and the model constant of samples contained in leaf i, respectively.
Next, to validate the result, before concluding the hypotheses for each node, we will perform a classical assumption test on the linear model generated based on samples on each leaf node. In this case, however, due to the nature of the algorithm, which splits the data by minimizing the variance, the data is no longer panel data but closely resembles cross-sectional data. Thus, the autocorrelation assumption is omitted as it is satisfied automatically.

Table 1 The splitting criterion for each node

N° Node	Condition
Node 4	Firm size < 28.52
Node 5	28.52 ≤ Firm Size < 29.45
Node 6	29.46 ≤ Firm Size < 30.49
Node 7	Firm size ≥ 30.49

5. Result and Discussion

In this section, we presented the results obtained from the numerical simulations. In particular, we will start the discussion by presenting the results obtained from the overall model, such as the tree structure and the Gini index, which offer information about the most important variable.
Next, we will interpret the result for the model contained in each leaf. This model needs to pass the classical assumption test, which is: normality via the Kolmogorov-Smirnov test, heteroscedasticity via the Breusch-Pagan test, and variance inflation factor. As in the previous explanation, the

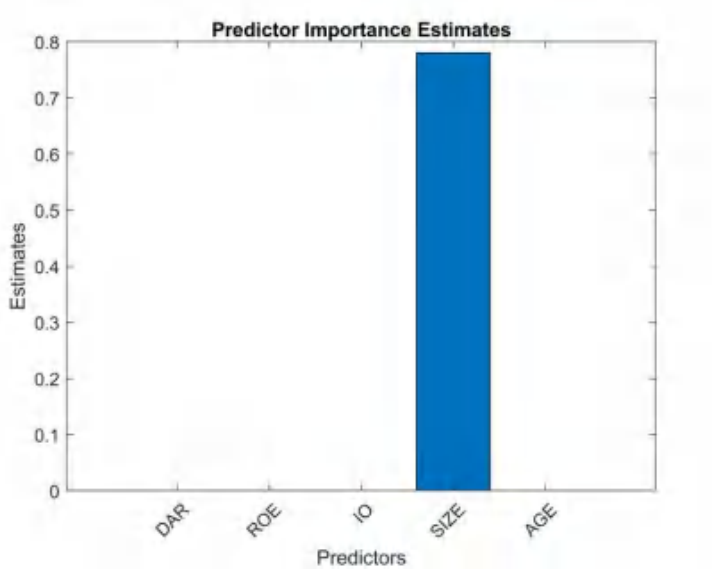


Figure 2 The plot of the Predictor importance estimate. It can be seen that the only predictors which strongly affected the data is the firm size

Table 2 The classical assumption test for 4 nodes. The autocorrelation test is omitted due to the data in each node is no longer sorted chronologically (i.e., no longer panel data)

Test	Node 4	Node 5	Node 6	Node 7
Normality (Kolmogorov-Smirnov)	0.38	0.91	0.60	0.81
Heteroscedasticity (Breusch-Pagan)	0.97×10^{-2}	0.15	0.24	0.90
Multicollinearity (VIF)				
DAR	2.27	1.36	1.42	1.83
ROE	2.07	1.66	1.11	2.56
IO	1.14	1.03	1.23	1.38
SIZE	1.24	1.17	1.22	1.20
AGE	1.15	1.47	1.29	1.81
Conclusion	Failed (BP-test)	Passed	Passed	Passed

***significant at alpha = 5%**

autoregressive test is omitted from the test, since the data is no longer panel data due to the regression tree split. We constructed the tree in such a way that each node contains at least 50 samples, to make the analysis meaningful (i.e., to satisfy the central limit theorem).

5.1 Overall Model Analysis

Figure 1 shows the regression tree model for the data, while Figure 2 shows the result of the parameter importance estimate based on the Gini Index. From Figure 1, it can be seen that the whole dataset is divided into 4 different leaf nodes, namely nodes 4, 5, 6, and 7. Table 1 summarizes the result of the splitting criterion for each node. In particular, from Table 1, a firm is considered in node 4 if the firm size is less than 28.52. It is considered in node 5 if the firm size is between 28.52 and 29.45, while it is in node 6 if the firm size is between 29.46 and 30.49. Finally, a firm is considered to be in node 7 if the firm size is greater than 30.49. From this information, it suggests that a firm is considered to be a small firm if the firm size is less than 28.52, while it is a big firm if it is greater than 30.49.

The next step is to check whether the model in each node satisfies the classical assumption. This process is needed to ensure that the result obtained in this node is not affected by any bias or external effect that is not considered in the model. Table 2 summarizes the classical assumption test results for all 4 nodes. From Table 2, all nodes passed the classical assumption test, except node 4, where the heteroscedasticity test of the node shows a significant result (i.e., there is a heteroscedasticity issue with the residual). Therefore, while the result for node 4 will still be presented, it is worth noting that the analysis drawn from this node might not be reliable.

Table 3 The ANOVA and Model Test for Node 4

Model Significance					
F test	13.6 (p-value = 1.26×10^{-9})				
r^2	0.613				
$N°$ sample	81				
ANOVA					
Parameter	**Max**	**Min**	**Variance**	**Estimate**	***p*-value**
DAR	0.950	0.098	0.047	0.371	0.420
ROE	0.274	-1.480	0.082	0.665	0.048
IO	1.000	0.364	0.025	0.318	0.475
Size	28.505	26.647	0.221	1.013	6.91×10^{-9}
Age	39.000	1.000	118.780	-0.015	0.028
Intercept	-	-	-	-0.315	0.942

***significant at alpha = 5%**

It is worth noting, however, that all nodes passed the normality test. This result shows that the RT algorithm can be used to split the data while maintaining the normality of the dataset. In particular, the proposed method can be used as an alternative to panel data analysis, which often requires a significant amount of knowledge in time series analysis.

5.2 Node 4: Firm size < 28.52

Table 3 shows the result of the ANOVA and the F-test for the model in node 4. From Table 3, we can see that the model is significant (i.e., better than a constant model) with r-squared (r^2) of 0.613. From the model, out of 5 parameters, there are 3 significant parameters: the ROE, size, and age.

For a small enterprise, in this case characterized by a firm size less than 28.52, the increment of the firm size is associated with a higher EV. Investors most likely perceive size as a proxy for resource capacity, market presence, and stability, thereby reinforcing its importance for small enterprises. The same could be said for ROE, which correlates significantly positively with the EV. As expected, investors valued more companies that were generous to the shareholders and able to bring more income.

On the contrary, age correlates negatively with EV. This indicates that firms in this cluster are considered to be interesting if they are relatively young. In the sense that the investor valued smaller

companies more than older small companies. This result reflects the preference of investors who prefer innovative and more agile companies.
Meanwhile, the DAR and IO are not significant for this cluster of data. The insignificance of DAR is most likely due to the relatively uniform leverage level, which is not considered a major risk for smaller companies. Similarly, smaller companies tend to have a similar level of ownership, which does not significantly affect the EV. Overall, this result indicated that small companies in Indonesia's EV are controlled by ROE, size, and age. While the capital structure and ownership characteristics play a lesser role.
Therefore, only H_1 and H_4 are accepted for small-sized companies, while the rest of the hypotheses are rejected.

5.3 Node 5: 28.52 ≤ Firm Size < 29.45

Table 4 shows the regression result for data in node 5, which is for companies with a firm size between 28.52 and 29.45. The model is significant, with r^2 of 0.358. As in the previous case, ROE, size, and age are still significant, with the addition of IO, which is significant at α=10%.
First, the ROE is still considered a significant factor for the EV for medium-range enterprises. This shows that investors are interested in companies that can generate large returns for them. The same can be said for the size, where growth in size is valued positively by the market. In contrast to node 4, age in node 5 correlates positively with EV. This shows that investors value experience in managing an enterprise for medium-sized enterprises. In particular, this indicates that investors prefer medium-sized firms with a longer operational history, as they are seen to be able to generate consistent returns and maintain sustainable growth.

Table 4 The ANOVA and Model Test for Node 5

Model Significance					
F test	7.82 (p-value = 6.83×10^{-6})				
r^2	0.358				
N° sample	78				
ANOVA					
Parameter	**Max**	**Min**	**Variance**	**Estimate**	***p*-value**
DAR	0.967	0.106	0.049	0.326	0.310
ROE	1.052	-2.549	0.243	0.569	0.001
IO	0.979	0.214	0.044	0.578	0.052
Size	29.448	28.525	0.068	0.750	0.004
Age	42.000	3.000	101.180	0.017	0.024
Intercept	-	-	-	6.739	0.360

***significant at alpha = 5%**

While it is insignificant at 0.05, the IO exhibits borderline significance for medium-sized enterprises. This result suggests that institutional investors may play a more prominent role in the valuation of medium-sized firms. This might be an indication as well that investors are interested in firms that maintain high governance standards and stability, which in this case is more likely to be found than in the previous case (i.e., small firms).
Overall, the results presented in this node show that ROE, size, and age remain significant in affecting the EV. Also, the IO seems to be positively correlated to the EV, even though it is only significant at α=0.1. This highlights the importance of growth, profitability, and experience in driving the value of the firm for this node. Concerning the hypotheses, only H_1, H_4 and H_5 are accepted for mid-sized companies, while the rest are rejected.

5.4 Node 6: 29.46 ≤ Firm Size < 30.49

Table 5 shows the summary of the results obtained from the regression model in node 5. Unlike in the previous node, the model in this node is insignificant. Hence, the result presented in this model might not be worth discussing, as the linear model failed to present the dynamics of the data in this node.The result presented in Table 5 is due to the fact that the nature of the data cannot be properly captured by

this node. In particular, this node can be considered a 'transition node', which is a node that contains a collection of firms that do not align properly with behavioral patterns in other nodes. The firms in this node exhibited a heterogeneous pattern or underlying irregularities, such as latent outliers that obscure

Table 5 The ANOVA and Model Test for Node 6

Model Significance					
F test	1.54 (p-value = 0.193)				
r^2	0.141				
$N°$ sample	53				
ANOVA					
Parameter	**Max**	**Min**	**Variance**	**Estimate**	***p*-value**
DAR	1.188	0.119	0.065	0.608	0.065
ROE	2.555	-1.103	0.201	-0.117	0.474
IO	0.925	0.173	0.032	-0.684	0.118
Size	30.490	29.467	0.094	0.335	0.183
Age	33.000	5.000	75.227	0.015	0.106
Intercept	-	-	-	19.996	0.010

***significant at alpha = 5%**

any systematic relationship between predictors and the EV. As such, node 6 might be best interpreted as a transitional node or unstable segment of the data. Thus, there is no need to test the significance of hypotheses for this node.

5.5 Node 7: Firm size ≥ 30.49

Table 6 presents the result of the regression analysis for node 7, which is a node considered to be a collection of big firms (i.e., firm size greater than 30.49). The regression model for node 7 is highly significant, as reflected by a very low model p-value and r^2 of 0.712. out of 5 predictors, only age is the predictor that does not affect the EV of this node.

As in the previous node, the ROE and firm size remain significant predictors of the EV. This result is pretty much expected for big companies due to their potential to generate profits. Interestingly, only in this node is the DAR significant and correlates negatively with the EV. This suggests that investors are more sensitive to the financial structure at this scale, due to the debt sustainability in larger balance sheets. Furthermore, IO, which is a parameter that is not significant in the previous nodes,

Table The ANOVA and Model Test for Node 7

Model Significance					
F test	34.1 (p-value = 2.21×10^{-17})				
r^2	0.712				
$N°$ sample	75				
ANOVA					
Parameter	**Max**	**Min**	**Variance**	**Estimate**	***p*-value**
DAR	0.782	0.240	0.023	-2.351	7.56×10^{-6}
ROE	1.451	-0.131	0.117	2.549	4.30×10^{-15}
IO	0.925	0.301	0.028	-1.249	0.002
Size	32.826	30.498	0.362	0.762	6.93×10^{-11}
Age	41.000	7.000	87.955	-0.009	0.246
Intercept	-	-	-	9.604	0.003

***significant at alpha = 5%**

appears to be significant and negatively correlated with the EV. This might be an indication that the investors avoided large companies with a lot of owner involvement, potentially reducing external investors' confidence.

Another interesting result comes from the age, in which age is insignificant to this node, contrary to the previous nodes. This indicates that age does not matter for big companies, as such enterprises have been proven to be able to generate large profits for the investor. In general, for large companies, the firm value is mostly shaped by profitability, financial structure, and ownership characteristics, and

these factors are considered to be "interesting" for investors. For the hypotheses, only H_1 and H_4 are accepted, while the rest are rejected.

5.6 Discussion

In this paper, we considered a novel method to analyze how financial parameters such as DAR, ROE, firm size, age, and IO affect the firm value or EV by leveraging the RT from the CART algorithm. The RT has successfully segmented the dataset into 4 different clusters, which can be identified based on their firm size.

For small enterprises, in this case, represented by node 4, it was revealed that ROE, age, and firm size were the significant predictors of the dynamics of the EV. ROE and firm size positively affect the EV, suggesting that the profitability and the marginal increase in the size of companies boosted the investors' interest in such companies. Interestingly, age correlates negatively with the enterprise value, suggesting that investors prefer young companies, which are often considered to be more agile and bring more innovation. Furthermore, DAR and IO do not affect the EV for small enterprises. In particular, this phenomenon is due to the leverage and ownership patterns in small enterprises.

For medium-sized enterprises, ROE, age, and firm size appear to be significant variables in predicting the EV, as in the previous case. However, unless in the previous case, the age correlates positively with the EV. This indicates that investors preferred more experienced companies for medium-sized firms. Also, in this case, the IO seems to affect these kinds of firms, although it is only significant at a 90% confidential level. This result indicates that the ownership role in medium-sized companies has begun to draw the attention of investors.

Finally, for large-sized firms, all predictors except age significantly affect the EV. In particular, the DAR has become negatively correlated to the EV, emphasizing that the leverage risk becomes critical at large-scale companies. The IO has also become negatively correlated to the EV, indicating that the ownership role in companies may be viewed as a government risk in large companies. Age, however, has lost its significance to the EV for large companies, hinting that maturity concerns less as a firm grows into a large firm.

In summary, it can be concluded that the influence of predictors depends on the firm size. Specifically, ROE and firm size constantly affect the EV in positive ways, while the age changes depending on the firm size. This pattern validates the use of the RT to uncover non-linear and context-specific relationships among variables. By building several linear models within homogeneous samples, the methodology not only preserves statistical validity but also helps to enrich the analysis of companies' firm value in Indonesia.

6.Conclusion

This study bridges the gap between machine learning and classical econometrics by applying the RT algorithm to create partitions of data and assign a linear model to it. This approach allows for a meaningful interpretation of how DAR, ROE, firm size, age, and IO affected the EV based on the firm size.

This result indicates that firm size is a critical variable in determining the relevance of financial predictors. In particular, ROE and firm size maintained strong positive effects on the EV, while the variables DAR and IO only affected the EV in large-scale companies. Also, the importance of age seems to decline as companies grow, hinting that the age of companies only matters for younger companies.

Overall, the integration of tree-based segmentation with linear models demonstrates a powerful analytical framework that is useful in handling heterogeneous data, which is considered to be a challenge for the classical approach. Future work might explore the inclusion of interaction effects or the application of similar frameworks to other emerging markets and financial environments.

References

Ahmed, A. M., Sharif, N. A., Ali, M. N., & Hágen, I. (2023). Effect of firm size on the association between capital structure and profitability. *Sustainability*, 15(14), 11196. https://doi.org/10.3390/su151411196

An, C., Cheh, J. J., & Kim, I. (2017). Do Value Stocks Outperform Growth Stocks in The US Stock Market? *Journal of Applied Finance and Banking*, *7*(2), 99.

Anita, R., & Abdillah, M. R. (2023). Leverage on Firm Value: The Role Of Financial Performance Mechanisms. *Journal of Application Business & Management/Jurnal Aplikasi Bisnis dan Manajemen*, 9(3). https://doi.org/10.17358/jabm.9.3.751

Asif, Ammara, and Dr. Bilar Aziz, (2016), Impact of Capital Structure on Firm Value Creation-Evidence from the Cement Sector of Pakistan, *International Journal Of Research In Finance And Marketing*, 6(6)

Ben Ltaief, Khouloud, and Hanen Moalla. The impact of financial assets' classification according to IFRS 9 on firm value: the case of MENA region's banks. *Journal of Financial Reporting and Accounting* 24.1 (2026): 66-96. https://doi.org/10.1108/JFRA-01-2023-0035

Bhullar. Pritpal Singh, (2017), Empirical Analysis of Operating Efficiency and Firm Value: A Study of Fast-Moving Consumer Goods and Pharmaceutical Sector in India*, International Journal of Economic and Financial Issues, Vol. 7 No. 3*, Econ Journals. https://izlik.org/JA68KJ38AX

Brigham, E. F., & Houston, J. F. (2021). *Fundamental of Financial Management* (16e ed.). Cengage Learning.

Bui, T. N., Nguyen, X. H., & Pham, K. T. (2023). The effect of capital structure on firm value: A study of companies listed on the Vietnamese stock market. *International Journal of Financial Studies*, 11(3), 100. https://doi.org/10.3390/ijfs11030100

Damodaran, Aswath, (2014), *Applied Corporate Finance*, Fourth Edition, WileyDjaja, Irwan, (2017), *All About Corporate Valuation, Memetakan, Menciptakan, Mengukur, dan Merealisasikan Nilai Perusahaan*, Elex Media Computindo, Jakarta.

Ferriswara, D., Sayidah, N., & Agus Buniarto, E. (2022). do corporate governance, capital structure predict financial performance and firm value? (empirical study of Jakarta Islamic index). *Cogent Business & Management*, 9(1), 2147123. https://doi.org/10.1080/23311975.2022.2147123

Hirdinis M., (2019), Capital Structure and Firm Size on Firm Value Moderated by Profitability, *International Journal of Economis And Business Administration*,7(1), Hal 174-191. https://www.um.edu.mt/library/oar/handle/123456789/43966

Irawan, D. C., Pulungan, N. A., Subiyanto, B., & Awaludin, D. T. (2022). The Effect of Capital Structure, Firm Size, And Firm Growth on Profitability And Firm Value. *Quality-Access to Success*, 23(187). https://doi.org/10.47750/QAS/23.187.06

Jerab, Daoud, *The Effect of Organizational Structure on Corporate Governance* (August 23, 2023). Available at SSRN: https://ssrn.com/abstract=4549766

Jhang, S.-S. (Sherwin), Lin, W. T., & Fang, I.-H. (2020). How Does Firm's Integrated Market Power Affect Upstream Trade Credit and Institutional Ownership? Evidence from Taiwan. *Asia Pacific Management Review*, *25*(2), 75–86. https://doi.org/10.1016/j.apmrv.2019.08.001

Lambey, R. (2021). The Effect of Profitability, Firm Size, Equity Ownership and Firm Age on Firm Value (Leverage Basis): Evidence from the Indonesian Manufacturer Companies. *Archives of Business Research*, *9*, 128–139. https://doi.org/10.14738/abr.91.9649

Lestari, L. (2017). Pengaruh Kepemilikan Institusional dan Struktur Modal Terhadap Nilai Perusahaan. *Jurnal Riset Manajemen Dan Bisnis*, *2*(Manajemen), 293–306.

Li, S., Hoque, H., & Liu, J. (2023). Investor Sentiment and Firm Capital Structure. *Journal of Corporate Finance*, *80*, 102426. https://doi.org/10.1016/j.jcorpfin.2023.102426

Lubis, I. L., Sinaga, B. M., & Sasongko, H. (2017). Pengaruh Profitabilitas, Struktur Modal, dan Likuiditas Terhadap Nilai Perusahaan. *Jurnal Aplikasi Bisnis Dan Manajemen (JABM)*, *3*(3), 458.

Mareta, F., Ulhaq, A., Resfitasari, E., Febriani, I., & Elisah, S. (2022, February). Effect of debt to equity ratio, current ratio, total assets turnover, earning per share, price earning-ratio, sales growth, and net profit margin on return on equity. *In International conference on economics, management and accounting* (ICEMAC 2021) (pp. 417-426). Atlantis Press. 10.2991/aebmr.k.220204.047

Maulana, I., Haryadi, B., & Arief, M. (2022). The Corporate Governance Mechanism on Earnings Management and Firm Performance. *AKRUAL: Jurnal Akuntansi*, *14*(1), 1–16. https://doi.org/10.26740/jaj.v14n1.p1-16

Ross, S. A., Jordan, B. D., & Westerfield, R. (2022). *Fundamentals of corporate finance* (13th ed.). McGraw-Hill Education.

Ross, Stephen A., et al, (2015), *CORPORATE FINANCE: Core Principles and Applications*, Asia Global Edition, Fourth Edition, McGraw-Hill Education, New York.

Rujiin, C., & Sukirman, S. (2020). The Effect of Firm Size, Leverage, Profitability, Ownership Structure, and Firm Age on Enterprise Risk Management Disclosures. *Accounting Analysis Journal*, *9*(2), 81–87. https://doi.org/10.15294/aaj.v9i2.33025

Salehi, M., Zimon, G., Arianpoor, A., & Gholezoo, F. E. (2022). The impact of investment efficiency on firm value and the moderating role of institutional ownership and board independence. *Journal of Risk and Financial Management*, 15(4), 170. https://doi.org/10.3390/jrfm15040170

Saputra, H. G., & Fachrurrozie. (2015). Determinan Nilai Perusahaan Sektor Property, Real Estate, & Building Construction Di BEI. *Accounting Analysis Journal*, *4 (2)*. https://doi.org/10.15294/aaj.v4i2.7848

Satrio, A. B. (2022). Firm Value in Indonesia: Will Foreigners be the Determinant? *JDM (Jurnal Dinamika Manajemen)*, *13*(1), 134–145.

Sui, X., Jiao, S., Wang, Y., & Wang, H. (2024). Digital transformation and manufacturing company competitiveness. *Finance Research Letterss*, 59, 104683. https://doi.org/10.1016/j.frl.2023.104683

Susanti, N., & Restiana, N. G. (2018). What's The Best Factor to Determining Firm Value. *Jurnal Keuangan Dan Perbankan*, *22*(2), 301–309.

Ummah, D. R., & Yuliana, I. (2023). Liquidity Relations, Current Ratio, Profitability, Gender Diversity, Company Size, and Company Value: Studies in Indonesia. *Jurnal Keuangan Dan Perbankan*, *27*(1), 81–95.

Wu, S., Li, X., Du, X., & Li, Z. (2022). The impact of ESG performance on firm value: The moderating role of ownership structure. *Sustainability*, 14(21), 14507. https://doi.org/10.3390/su142114507

Yundhari, Ni Wayan Trisna, Ida Bagus Panji Sedana, (2020), The Effect of Profitability, Growth, And Asset Structure On Company Value With Capital Structure As Mediation On Consumer Goods Companies In Indonesia Stock Exchange, *International Journal Of Business Marketing And Management,* Vol 5, No. 11.

To cite this article: Safaa Shaaban. (2026). *Village Savings and Loan Associations (VSLAs) in promoting and financial empowering Female Entrepreneurs in Egyptian rural areas, Journal of Financial and Economic Dynamics,* 1(1), 32-40; https://doi.org/10.66361/jfed.48

Village Savings and Loan Associations (VSLAs) in promoting and financial empowering Female Entrepreneurs in Egyptian rural areas

Safaa Shaaban
Business department, BA EPS, The British University in Egypt, Cairo 11837, Egypt
**Corresponding author: Safaa Shaaban,Safaa.Shaban@bue.edu.eg*

Abstract: This paper's primary goal is to investigate how the Village Saving and Loans Association (VSLA) promotes micro-entrepreneurship and Female Entrepreneurs as the primary strategy for small and micro enterprises in rural Egypt led by Female. The total sample size for both the quantitative and qualitative phases was 150 women. All 150 participants completed the survey, and 50 women were subsequently selected from this group to participate in in-depth interviews.in upper Egypt communities who followed the VSLA methodology were surveyed using semi-structured questionnaires as part of a mixed methods approach. In contrast, the quantitative approach depended on secondary data, including the results of knowledge, Attitude, and Practices (KAP). Multiple regression and thematic analysis were used to examine the gathered data. The Village Savings and Loan Association (VSLA) strategy has significantly improved the entrepreneurship of women and their startup and SME projects, according to the study's findings. The VSLA model helped members make creative entrepreneurs start up meeting the needs of their community and well-informed decisions about the growth of their small and medium company (SME) initiatives by reducing financial stress. The findings only apply to the sample that has participated in the VSLA project implemented by an international donor. A longitudinal quantitative evaluation of the VSLA approach and its impact on SD strategy of Egypt would be recommended in terms of further research study, highlighting the role of VSLA's impact on achieving the Egyptian sustainable strategy 2030. This paper is unique in presenting the concept of the VSLA as an intervention and approach for entrepreneurship in the rural community by empowering marginalized women facing financial hardship in upper Egypt. Although this approach has been used by international donors as part of large programs implemented in Egypt and other countries since 1979 aimed at SD in rural areas, There is scarcity in the literature related to this approach.

Keywords: Entrepreneurship, VSLA, Economic empowerment, Egyptian community;

1. Introduction

Rural women play a pivotal role in driving the social transformations necessary to achieve sustainable development (SD) in rural areas. Despite this, they still must deal with a few serious issues in Egypt's rural areas, such as low social standing, unstable finances, limited credit availability, poor healthcare, and a lack of educational possibilities. Global food and economic problems, climate change, and environmental degradation exacerbate these challenges.

Therefore, empowering rural women is crucial for promoting sustainable development throughout Egyptian society as well as improving the well-being and environmental quality of people, families, and rural communities.

Due to scarce resources and rising economic demands, rural communities face several difficulties. A more efficient substitute for centralized microfinance banks, the Village Savings and Loans Association (VSLA) model tackles many of these challenges and has great potential to assist the poorest and most disadvantaged rural populations. Fundamentally, the VSLA idea enables people to become their own bankers. It is completely self-sufficient and ideal for settings in the informal sector since it does not depend on outside borrowing or contributions to maintain its loan portfolio.

Because VSLAs don't require any formal bookkeeping, illiterate people in rural areas can use them. They offer a variety of flexible financial options, such as loans with customizable terms and repayment conditions, unlimited withdrawals, and variable savings. A single organization typically has 15 to 30 members who make modest weekly contributions to a fund that helps with both personal and societal concerns (Shaaban, 2022). In addition to providing financial assistance, VSLAs create networks and social capital that can boost the confidence of entrepreneurial women, promote joint ventures, and offer unofficial mentoring and support systems, all of which improve the viability of businesses in rural areas. Therefore, among rural households, involvement in VSLAs has been experimentally associated with increased business development, longer business survival, and higher profitability (Musinguzi, 2016).

Problem Statement This study compares the framework of women's long-term disadvantages in their rural Egyptian society with their financial emancipation. These drawbacks are evident in a variety of contexts, including the political, sociocultural, and economic spheres. In this sense, empowerment is giving women more financial independence and authority over their lives, families, and communities.

This study's main goal is to investigate how Village Savings and Loans Associations (VSLAs) promote micro-entrepreneurship as a crucial tactic for assisting Small and Micro Enterprises (SMEs) in rural Egypt.

"How do Village Savings and Loan Associations (VSLAs) foster micro-entrepreneurship in rural areas of Egypt?" is the primary research topic.

2. Literature Review

2.1 Village Saving and Loans Association (VSLA) concept

Due to scarce resources and financial strains, rural areas in Egypt frequently confront serious difficulties (Shaaban, 2022) . Unlike centralized microfinance banks, the Village Savings and Loan Association (VSLA) model effectively supports the poorest and most marginalized rural populations while addressing many of these challenges. Fundamentally, the VSLA idea enables people to become their own bankers. It is completely self-sufficient and does not depend on outside borrowing or contributions to maintain its loan portfolio. Because of this, the model easily fits into settings in the unorganized sector. Even illiterate individuals of rural communities can use VSLAs because they function in a simplified, informal manner and need less formal bookkeeping (Shaaban, 2022).

Members may contribute up to three shares every week under the VSLA concept, which is based on the idea of pooled contributions. Each group sets the maximum number of members allowed to contribute each week as well as the monetary value of a share. One important aspect of the system is that even the poorest people in rural communities can join because the share value is purposefully kept low. The VSLA's cash box, which is locked with three padlocks, protects the collective capital. To ensure openness and avoid abuse, the keys are divided among several group officers (Shaaban, 2019) . This VSLA mechanism guarantees that loans can be denied to non-members, including close family members like spouses, and improves transparency (Allen, 2006).

Most VSLA loans are short-term, generally lasting around one month. The interest rate is collectively agreed upon by group members and is typically set at 5% per month—substantially lower than the rates imposed by informal moneylenders, who may charge up to 30% monthly (Mutesasira, 1999) & (Shaaban, 2022) . Each VSLA group defines its own repayment terms, and the financial management skills acquired through this process play a crucial role in advancing women's economic empowerment within rural Egyptian communities (Shaaban, 2019) . The existing body of research on VSLAs in Egypt has largely consisted of program and project documentation, such as mid-term and final reports, with relatively few scholarly studies offering in-depth analysis. This study therefore

highlights the significant contribution of the VSLA model as a driver of rural sustainable development, women's economic empowerment, and broader transformations in equality, social structures, and cultural practices across rural Egypt.

2.2 The Entrepreneurial Mindset Model Based on Metacognitive Dimensions Model

Recent research in entrepreneurship has increasingly emphasized the pivotal role of cognitive and metacognitive processes in influencing entrepreneurial behavior. A particularly comprehensive framework in this area is presented by Hisrich, Peters, and Shepherd in their work *Entrepreneurship* (12th Edition) (Hisrich, Peters, & Shepherd, 2022) , where the entrepreneurial mindset is defined through a set of key metacognitive dimensions. The dimensions are Goal Orientation, Metacognitive Knowledge, Metacognitive Experience, Metacognitive Choice, and Monitoring. These dimensions represent core components that shape entrepreneurial thinking and behavior, especially when navigating uncertainty and complexity. This study will examine these only Goal Orientation, and Monitoring, As the other dimension is not applicable to rural women, this study explores how emerging entrepreneurs respond to challenges and opportunities.

2.2.1 Goal Orientation captures an entrepreneur's motivation and strategic commitment to achieving defined outcomes. As highlighted by Hisrich et al., individuals with strong goal orientation typically set ambitious goals, persist in overcoming obstacles, and engage in proactive, forward-looking planning. Within entrepreneurship research, goal setting is widely recognized as a central mechanism for strengthening self-regulation and sustaining long-term performance (Locke & Latham, 2002). In entrepreneurial practice, this orientation not only influences the trajectory of venture creation but also plays a pivotal role in shaping decision-making and identifying new opportunities.

2.2.2 Metacognitive Knowledge refers to an individual's awareness and understanding of their own cognitive processes, particularly in relation to entrepreneurial activity. This dimension involves recognizing personal strengths, limitations, and preferred approaches to problem-solving. Hisrich and colleagues note that successful entrepreneurs often draw upon accumulated knowledge from prior experiences and continuous learning, enabling them to adapt strategies to diverse and evolving circumstances. Such metacognitive awareness provides the foundation for strategic thinking and learning agility, both of which are essential for navigating the uncertainty inherent in entrepreneurial ventures.

2.2.3 Metacognitive Experience encompasses the emotions, judgments, and reflective processes that arise throughout the entrepreneurial journey. These experiences shape how entrepreneurs evaluate task difficulty, measure their performance, and adjust expectations accordingly. Hisrich et al. describe this dimension as both a cognitive and emotional checkpoint, where entrepreneurs critically assess past actions and outcomes to inform future decisions. Supporting this view, Ayne, Shepherd, Mosakowski, & Earley, 2010) demonstrate that reflective thinking significantly strengthens adaptive decision-making in uncertain and dynamic environments, a hallmark of successful entrepreneurial behavior.

2.2.4 Metacognitive Choice refers to the deliberate decisions entrepreneurs make regarding which cognitive strategies or tools to employ in specific contexts. This dimension emphasizes the intentional regulation of mental processes such as planning, problem-solving, and information seeking. Hisrich and colleagues argue that entrepreneurs who consciously select appropriate cognitive strategies are better positioned to navigate ambiguity and manage risk. This perspective aligns with theories of self-regulated learning and strategic thinking, suggesting that intentional cognitive control can substantially enhance entrepreneurial performance.

2.2.5 Monitoring entails the ongoing evaluation and regulation of cognitive processes throughout the entrepreneurial journey. Entrepreneurs must continuously track progress toward their goals, assess the

effectiveness of chosen strategies, and make timely adjustments when necessary. As noted by Hisrich et al., this continuous monitoring fosters adaptability and responsiveness, enabling entrepreneurs to pivot when initial approaches prove inadequate. Within entrepreneurship education, this skill is often cultivated through experiential learning and iterative feedback, encouraging individuals to critically reflect on their actions and outcomes to strengthen decision-making and overall performance.

Taken together, these five dimensions form a comprehensive metacognitive framework that equips entrepreneurs to operate effectively in uncertain and resource-constrained environments. Unlike traditional managerial roles, entrepreneurship demands heightened self-awareness, adaptability, and strategic reflection. This framework provides valuable insights for educators and practitioners, offering a foundation for designing training programs that enhance entrepreneurial cognition, foster self-regulation, and improve decision-making in complex and dynamic contexts.

Furthermore, the model serves as a robust basis for evaluating entrepreneurial potential for rural Egyptian women. Assessment tools that capture metacognitive awareness, goal-setting behaviors, and reflective practices can be applied in educational institutions, startup incubators, and recruitment processes to identify, nurture, and develop entrepreneurial talent.

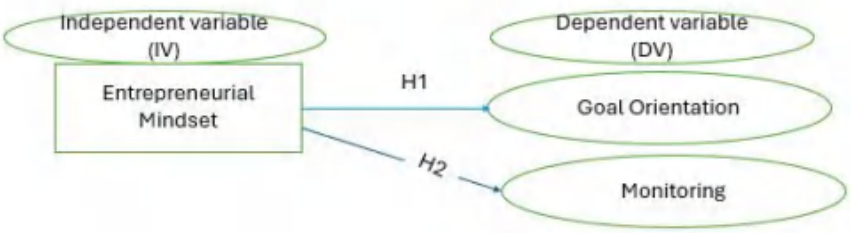
3. Research aims and Hypothesis:

The current research suggests that the VSLA approach supports women in starting entrepreneurship and launching creative startups. also this approach helps women to improve their financial situation and meet their hardship students because of lack of financial resources. To accomplish this objective, the following hypotheses will be examined:

H1: Entrepreneurial Mindset is positively and significantly related to Goal Orientation among Egyptian women.

H2: Entrepreneurial Mindset is positively and significantly related to Monitoring among Egyptian women.

3.1 Research model



3.2 Methodology

The aim of this study is to investigate the impact of VSLA as an approach on Empowering Grassroots Entrepreneurs for girls aged 30-45 for married and non-married women. The study applied structured and semi-structured interviews with women individually and in groups. The study applies two approaches: quantitative and qualitative. The total sample size for both the quantitative and qualitative phases was 150 women. All 150 participants completed the survey, and 50 women were subsequently selected from this group to participate in in-depth interviews.

3.2.1 Quantitative approach apply for 150 women applying the VSLA in Upper Egypt, questionnaire adapted from The survey instrument used in this study consists of 38 statements in Arabic divided into section one,which included demographic data including age and marital status; Section Two focused on goal orientation (five items).

section three Metacognitive Knowledge (included 11 statements); section four Metacognitive experiences (included 8 statements); section five Metacognitive Choice (including 5 statements); section six Monitoring (including 6 statements), the scale was adapted from the entrepreneurial mindset and cognitive characteristics frameworks developed by Robert D. Hisrich and Michael P. Peters (Hisrich, Peters, & Shepherd , 2022) . The items were selected and refined to reflect the cognitive patterns most relevant to women's mindset. Using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) to measure students' attitudes and self-perceptions related to entrepreneurship.

3.2.2 Qualitative approach, interviewing individuals and groups for 50 women, applying semi-structure interviews with individuals and focus group discussions. Applying participatory.

Table 1 Individual and group

No. of interviews		Total
individual	Groups (6)	
25	25	50 women

50 women that participated in the VSLA project were randomly selected. Table 1 shows the interview covered the following points in Arabic conversation, but not limited to the following questions

- What do you think of the VSLA approach in Egypt?
- How does VSLA help you to build your startup?
- How can this approach help your creativity when you choose your entrepreneurial project?
- Based on why you choose your start up project? And do you think we can say your project is creative and meets the needs of the community?

Over three consecutive days, the author conducted both individual and group meetings with the 50 women participants. The VSLA project team facilitated these sessions by arranging schedules and ensuring that all participants provided informed consent prior to participation. Over the course of four days, the author engaged with 50 women through both individual and group meetings. The VSLA project team facilitated the process by coordinating the sessions, confirming participants' availability, and ensuring that informed consent was obtained.

3.3 Data Collection

Data was gathered through a face-to-face survey that was translated into Arabic to ensure accessibility and facilitate women's participation. The survey was conducted during a consultancy field visit, with participation remaining entirely voluntary and anonymous.

3.4 Data Analysis

The data were analyzed using SPSS (Statistical Package for the Social Sciences, Version 26). The analysis included descriptive statistics, reliability testing through Cronbach's Alpha, and inferential techniques such as correlation analysis, regression analysis, and binary logistic regression to explore relationships between cognitive mindset variables and entrepreneurial attitudes. In addition, independent sample t-tests and ANOVA were employed to examine differences across gender, academic level, and country.

4. Study Result

4.1 Quantitative Result

Reliability Testing of the Variables

The subscales demonstrated acceptable internal consistency, with Cronbach's alpha coefficients surpassing the 0.6 threshold. Table 2 provides a detailed summary of the reliability analysis. As emphasized by (Hair, Black, Babin, & Anderson, 2016), reliability denotes the degree of measurement consistency across repeated assessments of the same construct. Variables that demonstrate higher levels of consistency are regarded as more reliable than those with weaker consistency.

Table 2 Study Variables Reliability

Scale	Cognitive mindset	Goal orientation	Monitoring
Alpha	.878	.832	.645

Sources: Author's work

Table Correlation between all study variables

	Mean	SD	CM	GO	M
CM	73.723	28.954	1		
GO	26.265	7.456	. 845**	1	
M	25.657	7.567	. 753**	.563**	1

Note. **Correlation is significant at the 0.01 level (2-tailed)

4.2 Cognitive Mindset (CM); Goal Orientation (GO); Monitoring (M)

As table 3 shows, the correlation analysis revealed significant positive relationships among all dimensions of the entrepreneurial mindset model at the 0.01 level. Metacognitive Choice demonstrated the strongest associations with Cognitive Mindset ($r = .953$, $p < .01$) and Monitoring was also strongly correlated with Metacognitive Choice ($r = .763$, $p < .01$) and Cognitive Mindset ($r = .753$, $p < .01$). These findings suggest that the dimensions operate as interrelated components of a comprehensive entrepreneurial mindset framework. However, the very high correlation between Cognitive Mindset and Metacognitive Choice may indicate potential multicollinearity and warrants further examination.

Table4 AVE Values

AVE Values					
	Std. β	t-value	Sig.	Reliability	
Entrepreneurs' components	0.976	16.253	***	AVE;	0.695
Cognitive Mindset (VSLA)	0.854	17.335	***	CR;	0.772
**. Coefficient is significant at the 01 level.					

As Table 4 shows, the measurement model results demonstrate strong validity and reliability for the study constructions. The standardized beta coefficients indicate very high factor loadings for Entrepreneurs' Components ($\beta = 0.976$) and Cognitive Mindset (VSLA) ($\beta = 0.854$), confirming strong relationships between the constructs and their respective indicators. Furthermore, the t-values (16.253 and 17.335, respectively) exceed the critical threshold, indicating that all loadings are statistically significant at the 0.01 level ($p < 0.01$). Regarding convergent validity, the Average Variance Extracted (AVE = 0.695) surpasses the recommended threshold of 0.50, confirming that the constructs explain a substantial proportion of the variance in their indicators. In addition, the Composite Reliability (CR = 0.772) exceeds the acceptable level of 0.70, demonstrating satisfactory internal consistency. Overall, these findings confirm that the measurement model exhibits adequate reliability and convergent validity, supporting its suitability for subsequent structural model analysis.

5. Discussion

The qualitative approach takes the shape of a "semi-structured interview" with individuals and groups of 60 women participating in VSLA groups headed by a mentor. The summary of their feedback regarding the following questions:

5.1 What do you think of the VSLA approach in Egypt?

All women who participated in the study confirmed that they believe the VSLA approach is very suitable for women in Upper Egypt. It provides a safe, community-based way to save money and access small loans without going through the bank procedures, which sometimes ended with rejection of their request. It also builds trust among women with each other and mentors, in addition, strengthens our financial independence. This can happen

through group meetings. They pointed out that they learn financial skills, planning, and how to manage our money better. Overall, VSLA gives us opportunities that we usually cannot get from banks.

5.2 How does VSLA help you to build your SMEs? Business/startup?

Around 90% of women agreed that the VSLA supported them in two main directions. First, the loan they received helped them secure the basic money they needed to start their startup idea, which something they could not get from a bank in their local areas. Second, the discussions between the group helped me progress my financial plan, record-keeping, and planning for my startup project. In addition to the support on the level of emotional and moral for each other by other women in the same group encouraged us to take the step toward launching our startup ideas with more confidence.

5.3 How can this approach help your creativity when you choose your enterprise project?

50% of women participated in the study, and they confirmed that VSLA encouraged them to think more creatively about business ideas. In their meetings, they share experiences, challenges, and new ideas, while the other 50% confirmed that, when they see the other successes in their ideas, they copy the idea in other areas of the villages. The new idea inspires them to look for what is missing in the market, and they start to work on it. What VLSA gave them access to small loans gave them the freedom to experiment with a startup that fit their knowledge, skills and interests.

5.4 Why did you choose your startup project? And do you think we can say your project is creative and meets the needs of your community?

Most women choose their startup because it reflects my skills and responds to a real need in my community. They know about it from friends and family. Mentors help us to study the local market and see that people need (e.g., clothes, groceries, handmade products, food services, tailoring, natural cosmetics), and they felt they could offer something different.

Village Savings and Loan Associations (VSLAs) can considerably encourage entrepreneurial activity among rural women by offering an accessible and community-based financial platform with trusted women from their communities. For example, a recent study titled Women entrepreneurship and village savings: a developing income route and approach a study conducted in 2025 shows that such “village savings” techniques help women entrepreneurs supported with capital and engage in income-generating enterprises, in that way they contribute to business creation and economic empowerment (Siwale, Simba , Frost , & Henry , 2025) . Also, research on micro- savings groups published in Financial Promise for the Poor: How Groups Build Micro Savings in 2013, they research notes that these savings groups reinforce financial inclusion through pooled savings, which lowers barriers to startup businesses for women lacking access to formal banking (Lombe, 2013) . In contexts where conventional credit is unavailable or inaccessible, VSLAs by combining savings, small loans, social support, and social solidarity thus provide a vital steppingstone to launch and sustaining micro-enterprises and smoothing the way for entrepreneurial ideas for small business services and satisfy their community needs.

According to the study, multiple accounts demonstrate that Village Savings and Loan Associations (VSLAs) help stimulate entrepreneurship and build economic resilience in rural areas by offering savings and credit options not typically accessible through formal banks. In Upper Egypt, a study by (Shaaban, 2022) found that women micro-entrepreneurs benefited from VSLA loans and group support, which encouraged business growth, financial independence, investment in assets, and improved the family's financial situation in general. Yet, limited financial literacy and gender-related obstacles prevented these enterprises from reaching their full potential (Achieng, 2025).

A major challenge for entrepreneurs in VSLAs is obtaining sufficient financing for business growth. While VSLAs offer savings and small loans, limited loan sizes and weak connections to formal institutions restrict access to larger capital. Complex loan requirements and few alternative credit options further impede sustainable expansion

6. Conclusion and implications

In the Egyptian community, one of the crucial tools to support entrepreneurs is VSLA, the main objective of this study was to explore how VSLAs advance micro- entrepreneurship as the main pathway for SMEs in rural Egypt. The study showed that VSLA is one of the most successful tools to create, empower, and support entrepreneurs in Upper Egypt

Empirical evidence highlights Village Savings and Loan Associations (VSLAs) as effective mechanisms for promoting entrepreneurship and economic empowerment in underserved rural communities. By offering accessible savings platforms and small-scale loans often unavailable through formal financial institutions, VSLAs have been linked to greater financial inclusion, income growth, and expanded opportunities particularly for women to invest in micro-enterprises and household income-generating activities (Shaaban, 2019) (CARE, 2024). Concluded enhanced access to capital and collective financial support, VSLA participation enables members to establish or expand small businesses, thereby strengthening local economic resilience and entrepreneurial activity in rural areas (CARE, 2024) . While empirical studies specific to Upper Egypt remain limited, broader development programs incorporating VSLA components have demonstrated positive impacts on livelihoods, financial decision making, and community engagement in comparable rural contexts, underscoring the potential of VSLAs to empower entrepreneurs in regions such as Upper Egypt.

The findings of this study involve significant implications on three levels: theoretical, practical, and policy. Realistically, the evidence indicates that Village Savings and Loan Associations (VSLAs) enforce the creation, empowerment, and support of entrepreneurs, underlining their value as a sustainable entrepreneurship grassroots financing model in place such as Upper Egypt. International development practitioners, donors, and non-governmental organizations can employ VSLAs as cost-effective, community-driven mechanisms to stimulate entrepreneurial activity, particularly among women and youth who face hardship in financial support and have limited access to formal financial services.

From the perspective of policy implications, the study highlights the prospect of integrating VSLAs into entrepreneurship and rural development national strategies to advance financial inclusion and strengthen local economic resilience. Politicians may boost the efficacy of VSLAs by investing in capacity-building initiatives for VSLA users, financial literacy programs in rural areas, and connections with formal microfinance organizations, thus enabling business creativity and growth outside the micro-enterprise level.

On the level of theoretical implications, this research study contributes to the entrepreneurship and microfinance literature by confirming the role of informal financial institutions in shaping entrepreneurial behavior within low-income rural contexts in the rural area in Egypt. Furthermore, highlights the significance of social capital and collective financial structures in addressing structural obstacles to entrepreneurship, and contributes a context-specific contribution relevant to Upper Egypt.

References

Lombe, M. (2013). Financial Promise for the Poor: How Groups Build Microsavings. *International Journal of Social Economics, 40*(3), 289–290. doi:doi: https://doi.org/10.1108/03068291311291545

Achieng, S. A. (2025). Village saving loan association membership and commercialization among smallholder maize farmers in northern Uganda. *Discov Agric, 3*(68). doi: https://doi.org/10.1007/s44279-025-00235-2

Allen, H. (2006). Village Savings and Loans Associations — sustainable and cost-effective rural finance. *Small Enterprise Development, 16*, 61-80.

aynie, J., Shepherd, D., Mosakowski, E., & Earley, P. (2010). A situated metacognitive model of the entrepreneurial mindset. *Journal of Business Venturing, 25*, 217-229. https://doi:10.1016/j.jbusvent.2008.10.001

CARE. (2024). *Microsavings through Village Savings and Loan Associations—impact evidence across savings groups.* CARE International.

Hair, J., Black, W., Babin, B., & Anderson, R. (2016). *Multivariate data analysis.* New Jersey, USA.: Pearson Prentice Hall Upper Saddle River,.

Hisrich, D. R., Peters, R. M., & Shepherd, A. D. (2022). *Entrepreneurship. 12th Edition,.* New York.: McGraw Hill,.

Hisrich, R. D., Peters, M. P., & Shepherd , D. A. (2022). *Entrepreneurship (12th ed.).* McGraw-Hill Education.

Locke, A. E., & Latham, P. G. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist, 57*(9), 705–717. https://doi.org/10.1037/0003-066X.57.9.705

Musinguzi, L. K. (2016). The role of social networks in savings groups: insights from village savings and loan associations in Luwero, Uganda. *Community Development Journal, 51*(4), 499–516. https://doi.org/10.1093/cdj/b

Mutesasira, L. (1999). *Use and Impact of Savings Services among the Poor in Tanzania,*. Microsave: Nairobi.

Shaaban, S. (2022), "Can village savings and loans association (VSLA) approach achieve/promote rural sustainable development in the Egyptian community?", Journal of Chinese Economic and Foreign Trade Studies, Vol. 15 No. 3, pp. 332-349. https://doi.org/10.1108/JCEFTS-08-2021-0047

Siwale, J., Simba , A., Frost , D., & Henry , P. (2025). Women entrepreneurship and village savings: a developing world perspective. *International Journal of Entrepreneurial Behavior & Research, ahead-of-print*(ahead-of-print). https://doi.org/10.1108/IJEBR

Akter, Sonia, and Namrata Chindarkar. (2020). "An empirical examination of sustainability of women's empowerment using panel data from India." *The Journal of Development Studies*, 56, (5): 890-906.

Al Mamun, A., Fazal, S. A., & Muniady, R. (2019). Entrepreneurial knowledge, skills, competencies and performance: A study of micro-enterprises in Kelantan, Malaysia. *Asia Pacific Journal of Innovation and Entrepreneurship*, *13*(1), 29-48.

Al-Ayouty, I., & Hassaballa, H. (2020). Towards sustainable development: measuring environmental total factor productivity in Egypt. *European Journal of Sustainable Development*, *9*(2), 55-55.

Bhattacharyya, A., & Kumar, N. (2020). Who is more entrepreneurial? A comparative study of vocational and academic students. *Asia Pacific Journal of Innovation and Entrepreneurship*, 14(1), 15-30.

Shaaban, S. (2018). Reviewing Egyptian community social fund (village savings and loans association, VSLA) as an approach for community social fund. *Horticulture International Journal*, 2(6), 13–18. https://doi.org/10.15406/hij.2019.03.00105

Miniesy RS, AbdelKarim M. (2021). Generalized Trust and Economic Growth: The Nexus in MENA Countries. *Economies*, 9(1):39. https://doi.org/10.3390/economies9010039

To cite this article : Mayadhar Sethy. (2026). *Between Prudence and Performance: Measuring Odisha's Fiscal Outcomes in the Era of the 15th Finance Commission, Journal of Financial and Economic Dynamics*, 1(1), 41-61; https://doi.org/10.66361/jfed.50

Between Prudence and Performance: Measuring Odisha's Fiscal Outcomes in the Era of the 15th Finance Commission

Mayadhar Sethy
ICSSR Doctoral Fellow, Development Studies, Nabakrushna Choudhury Centre for Development Studies, Bhubaneswar, Odisha , India
**Corresponding author: Mayadhar Sethy, mayadharsethyms@gmail.com*

Abstract: This study provides a comprehensive econometric outcome evaluation of Odisha's fiscal architecture under the 14th and 15th Finance Commissions (FC). Employing a multi-method framework including time-series analysis, tax effort estimation, and augmented Vector Autoregression (VAR) projections that explicitly account for mining revenue volatility, it traces the state's transformation from fiscal distress to exemplary prudence. Analysis of data (2000-01 to 2030-31) reveals consistent revenue surpluses, a steeply declining debt-to-GSDP ratio (14.9% in 2022-23), and high capital expenditure (27.4% of outlay). Odisha effectively leveraged FC-XV's performance-linked grants for disaster resilience, health, and local governance, with causal inference analysis (using a Two-Stage Least Squares approach with instrumental variables) indicating positive sectoral outcomes. Despite this, structural vulnerabilities endure, primarily from volatile mining revenues and underperformance in property tax mobilization, as identified by a critically re-evaluated Representative Tax System analysis. Robust projections from an augmented VAR model subjected to rigorous diagnostic checks and extreme stress-test scenarios affirm a sustainable fiscal trajectory, with the debt ratio remaining well below statutory limits. The findings indicate that Odisha's success is underpinned by strict adherence to FRBM principles and a strategic, growth-oriented expenditure composition. The conclusion emphasizes that sustaining this resilience requires continued innovation in revenue diversification, formal outcome-based monitoring systems, and institutional mechanisms like a stabilization fund to mitigate revenue volatility. The study offers critical, evidence-based insights for fiscal federalism and sub-national fiscal management in developing economies.

Keywords: 15th Finance Commission, Fiscal Federalism, State Finances, Odisha, Fiscal Discipline, Econometric Analysis, Debt Sustainability, Tax Effort

1. Introduction

India's framework of fiscal federalism is constitutionally anchored in the institution of the Finance Commission (FC), which is mandated under Article 280 of the Constitution to recommend the distribution of central tax revenues between the Union and the States (vertical devolution) and among the States (horizontal devolution). These recommendations are operationalized through a clearly specified, formula-based sharing mechanism that incorporates multiple criteria such as population, income distance, area, forest and ecology, and fiscal performance. Far from being neutral fiscal transfers, FC awards play a decisive role in shaping state-level fiscal behavior by influencing budgetary priorities, sectoral allocations, and investment decisions. Consequently, Finance Commissions function not merely as redistributive

institutions but as critical policy instruments that mediate national objectives and sub-national development outcomes.

The Fifteenth Finance Commission (FC-XV), whose award period spans from 2021–22 to 2025–26, was constituted under extraordinary macroeconomic and institutional conditions. Its deliberations coincided with the fiscal shock induced by the COVID-19 pandemic, heightened uncertainty in public revenues and expenditures, and the reorganization of the erstwhile state of Jammu and Kashmir. Within this context, FC-XV was tasked with reconciling the objectives of equity, efficiency, and fiscal sustainability. A defining feature of its recommendations was the explicit shift toward performance-linked and sector-specific grants, particularly in health, disaster management, and local government finance. This marked a structural transition from largely unconditional transfers toward a framework in which fiscal devolution was increasingly tied to measurable outputs and outcomes, embedding incentive compatibility within India's federal fiscal architecture.

Odisha represents a particularly instructive case for evaluating the outcomes of such a framework. Historically classified among India's fiscally stressed and disaster-prone states, Odisha's fiscal position during the late 1990s and early 2000s was characterized by persistent revenue deficits, a debt-to-GSDP ratio exceeding 54 percent, and frequent liquidity pressures that necessitated reliance on central overdrafts. Weak own-revenue capacity, high committed expenditures, and repeated natural calamities severely constrained the state's developmental spending, reinforcing a cycle of fiscal vulnerability.

A decisive turnaround occurred in the early 2000s following a series of institutional and fiscal reforms. Central to this transformation was the enactment of the Odisha Fiscal Responsibility and Budget Management (FRBM) Act in 2005, which introduced binding constraints on deficits and debt accumulation. These reforms were reinforced by successive Finance Commission awards that incentivized fiscal consolidation, enhanced transparency, and encouraged a reorientation toward capital expenditure. Over time, Odisha eliminated its revenue deficit, reduced its debt burden, and generated sustained revenue surpluses. By the onset of FC-XV, Odisha had emerged as a revenue-surplus state, rendering it ineligible for Revenue Deficit Grants while simultaneously underscoring its fiscal discipline. This fiscal position provides a unique empirical setting to examine the efficiency with which fiscal inputs are translated into developmental outcomes.

The FC-XV recommendations were particularly salient for Odisha. While the vertical devolution to states was maintained at 41 percent of the divisible pool, Odisha's horizontal share was fixed at 4.64 percent. This allocation reflected the Commission's emphasis on equity-oriented criteria such as Income Distance (assigned a weight of 45 percent) and Forest and Ecology (10 percent), the latter being especially relevant given Odisha's substantial forest cover. More importantly, FC-XV earmarked significant tied and performance-based grants for sectors in which Odisha faces acute vulnerabilities, including enhanced allocations to the State Disaster Response Fund (SDRF), performance-linked health sector grants, and grants for strengthening Panchayati Raj Institutions (PRIs) and Urban Local Bodies (ULBs).

Against this background, the present study undertakes a rigorous, econometrically grounded outcome evaluation of Odisha's fiscal performance under the Fourteenth and Fifteenth Finance Commissions. The analysis is guided by four core research questions. First, how has Odisha's fiscal architecture evolved in response to the recommendations of FC-XIV and FC-XV? Second, how efficient and effective has the state been in utilizing devolved funds and specific-purpose grants to achieve intended sectoral outcomes, as measured through robust causal inference methods? Third, is Odisha's current fiscal trajectory—particularly with respect to debt sustainability as modeled through an augmented Vector Autoregression (VAR) model that includes mining revenue volatility—consistent with long-term growth and macro-fiscal stability under various stress scenarios? Finally, what challenges and policy imperatives emerge for sustaining this fiscal resilience in the context of revenue volatility and structural constraints? By

addressing these questions, the study contributes a detailed empirical case study to the literature on fiscal federalism and sub-national public finance.

2. Literature Review

The scholarly literature on Indian fiscal federalism and state finances spans public economics, political economy, and development studies. This section synthesizes key strands relevant to evaluating fiscal outcomes following Finance Commission awards, with particular emphasis on econometric and modeling approaches.

The theoretical foundation of intergovernmental fiscal transfers lies in correcting vertical and horizontal imbalances while minimizing efficiency losses. In the Indian context, Rao and Singh (2005) conceptualize Finance Commission transfers as a political–economic equilibrium balancing equity objectives; operationalized through income distance and need-based criteria with efficiency incentives linked to fiscal discipline. Subsequent studies increasingly model these transfers as optimization problems that maximize welfare subject to fiscal and incentive constraints. The design choices of FC-XV have attracted considerable academic scrutiny. Chakraborty et al. (2020) analyze the Commission's decision to retain the 2011 Census for population weights, noting its implications for states that achieved early demographic transition. Bagchi (2021) characterizes FC-XV's emphasis on outcome-linked and sector-specific grants as a paradigmatic shift that necessitates rigorous post-facto evaluation using counterfactual and quasi-experimental econometric techniques.

A substantial body of empirical literature documents fiscal consolidation across Indian states following the adoption of FRBM legislation. Using panel econometric methods, Howes et al. (2017) identify Odisha as a leading performer, attributing its success to political commitment to fiscal rules, improved tax administration, and control over non-developmental expenditure. Jha (2018) emphasizes the role of buoyant non-tax revenues particularly mining royalties in financing capital expenditure, relationships often examined using Granger-causality tests and time-series regressions. However, reliance on resource-based non-tax revenue raises concerns regarding sustainability. Drawing on the resource curse literature, Reddy (2019) employs volatility modeling and unit root tests on revenue series to demonstrate the inherent instability of extractive revenues, underscoring the importance of evaluating revenue composition alongside fiscal outcomes.

The increasing use of performance-based grants under FC-XV mirrors global trends in results-based public financing. Ghosh (2021) highlights the methodological challenges associated with defining and measuring appropriate performance indicators in the health sector, advocating the use of Difference-in-Differences (DiD) designs. Sridhar (2022), in evaluating disaster management grants, argues that the flexibility of SDRF usage must be complemented by incentives for ex-ante risk reduction, a hypothesis testable through regression models with appropriate controls linking SDRF expenditure to disaster-related economic losses.

Debt sustainability is central to sub-national fiscal stability. Rangarajan and Srivastava (2008) propose an intertemporal budget constraint framework emphasizing indicators such as the debt-to-GSDP ratio. Recent RBI State Finance reports identify Odisha's declining debt burden as a marker of fiscal strength. Dash and Raja (2020) employ Panel Vector Autoregression (PVAR) models to capture dynamic interactions among growth, revenue, and expenditure, highlighting both the utility and limitations of VAR-based projections in the presence of shocks and policy breaks. Critically, their work underscores the need to include major revenue shock variables, like mining income, to avoid omitted variable bias in sustainability projections.

Fiscal autonomy depends critically on own-revenue mobilization. The concept of tax effort—defined as the ratio of actual tax collection to estimated taxable capacity—has been operationalized in India using

the Representative Tax System (RTS) and Stochastic Frontier Analysis (SFA). Building on the framework of Lotz and Morss (1967), recent studies by Jha et al. (2021) employ SFA to rank Indian states, often placing Odisha in the mid-range. Gupta (2007) emphasizes governance quality and administrative capacity as key determinants of tax effort, measurable through econometric indices. Importantly, the literature cautions that extreme tax effort indices (e.g., >>1) may signal data issues, such as an ill-defined tax base or statutory rates deviating significantly from the national average, rather than exceptional efficiency (Rao, 2000).

Despite extensive literature, there is a paucity of comprehensive post-facto evaluations that explicitly link state-level fiscal outcomes to specific Finance Commission recommendations over a medium-term horizon using multiple econometric tools. This study addresses this gap by integrating trend analysis, a critically examined tax effort estimation via RTS, and robust debt sustainability modeling via an augmented VAR within a unified analytical framework.

3. Data and Methodology

3.1 Data Sources

The primary fiscal dataset comprises time-series data from Odisha's Finance Accounts, Annual Budget Statements, and Medium-Term Fiscal Plan (MTFP) documents for the period 2000–01 to 2022–23. These provide authenticated figures on revenue receipts (Own Tax Revenue, OTR), Own Non-Tax Revenue (ONTR), with a detailed breakdown of Mining Revenue (MR), Taxes and Duties from the Centre (TCT), and Grants-in-Aid (GiA) as well as expenditure components, fiscal balances, and public debt. Finance Commission Reports (FC-XIV and FC-XV) serve as normative benchmarks. Macroeconomic data on Gross State Domestic Product (GSDP) are sourced from the Directorate of Economics and Statistics, Government of Odisha. Sectoral outcome indicators are compiled from NFHS-5, the India State of Forest Report, and Swachh Bharat Mission (Gramin) reports. Comparative data for 16 other major states are drawn from their Finance Accounts and the RBI Handbook of Statistics on Indian States. For causal inference on grants, data on cyclone intensity (Accumulated Cyclone Energy Index) and national policy dummies were compiled from the India Meteorological Department and relevant government notifications.

3.2 Analytical Framework and Econometric Methods

Longitudinal trends in key fiscal indicators (2000–01 to 2022–23) are analyzed and benchmarked against FC-XV targets and all-state averages. Structural breaks are identified using the Chow Test.

To assess grant effectiveness and address endogeneity concerns, a Two-Stage Least Squares (2SLS) instrumental variable approach was employed for disaster management grants. For health and local governance grants, where random assignment is absent, a multivariable regression framework with key controls was used to mitigate omitted variable bias. The general form of the outcome models is:

$$Outcome_t=\alpha+\beta_1 GrantExpenditure_t+\beta_2 ControlVariables_t+\varepsilon_t$$

For SDRF impact, the instrumental variable was a lagged national commodity price index (affecting central SDRF allocations but not Odisha-specific disaster losses), controlling for disaster intensity (wind speed, rainfall) and pre-existing infrastructure stock.

Tax effort is estimated using a modified Representative Tax System (RTS). Taxable capacity for tax head i, state s, and year $t$is estimated as:

$$TaxCapacity_{ist}=\tau_i^{national}\times Base_{ist}$$

Where $\tau_i^{national}$denotes the national average effective tax rate and $Base_{ist}$represents the relevant tax base. The Tax Effort Index (TEI) is computed as:

$$TEI_{ist}=\frac{ActualCollection_{ist}}{EstimatedCapacity_{ist}}$$

Debt sustainability is analyzed using an augmented Vector Autoregression (VAR) model:

$$Y_t=A_0+A_1 Y_{t-1}+A_2 Y_{t-2}+\cdots +A_p Y_{t-p}+\varepsilon_t$$

Where $Y_t = [\Delta \ln f_0(GSDP_t), \Delta \ln f_0(TRR_t), \Delta \ln f_0(TotEx_t)]$

Public debt is derived recursively as:

$PublicDebt_t = PublicDebt_{t-1} + (TotEx_t - TRR_t)$

Stationarity is tested using Augmented Dickey–Fuller (ADF) tests, and lag length is selected using AIC and SBIC criteria. Model adequacy is confirmed through Lagrange Multiplier (LM) tests for residual autocorrelation and White tests for heteroscedasticity. A comprehensive stress-testing regimen was implemented, including: (i) a combined shock scenario (15% MR decline, 1 pp GSDP growth reduction, 20% disaster exp. increase); (ii) an extreme disaster scenario (50% MR decline for two consecutive years); and (iii) a prolonged growth slowdown scenario.

4. Results

4.1 The Fiscal Turnaround: A Longitudinal Perspective

Odisha's fiscal journey is one of the most pronounced among Indian states. The econometric analysis confirms a significant structural break in its fiscal series around 2004-05, aligning with the passage of its FRBM Act (Chow Test F-statistic: 12.47, $p < 0.01$). As depicted in Figure 1, the debt-to-GSDP ratio peaked at 54.4% in 2002-03, signaling severe stress. Concerted efforts led to a steep and consistent decline, with the ratio falling to 14.9% by 2022-23 one of the lowest in India. This decline is statistically significant ($p < 0.001$) and follows a quadratic trend, indicating accelerating improvement post-2010. This was underpinned by the emergence of a consistent revenue surplus from 2005-06 onwards (Figure 2). The post-2014 period saw an acceleration in CapEx, with its share in TotEx showing a significant positive trend ($\beta = 0.87$, $p < 0.01$), reflecting the state's strategic shift towards infrastructure-led growth.

This figure illustrates Odisha's dramatic fiscal transformation from 2000-01 to 2022-23, showing debt-to-GSDP ratio declining from ~50% to 14.9%—one of the lowest in India. The steep downward trajectory contrasts with the gentler decline in all-state averages, highlighting Odisha's exceptional performance. Structural breaks align with FRBM implementation (2005) and FC-XV recommendations, demonstrating policy effectiveness. The convergence pattern validates Odisha's transition from fiscal distress to exemplary prudence, providing visual evidence of sustained commitment to debt sustainability through disciplined fiscal management.

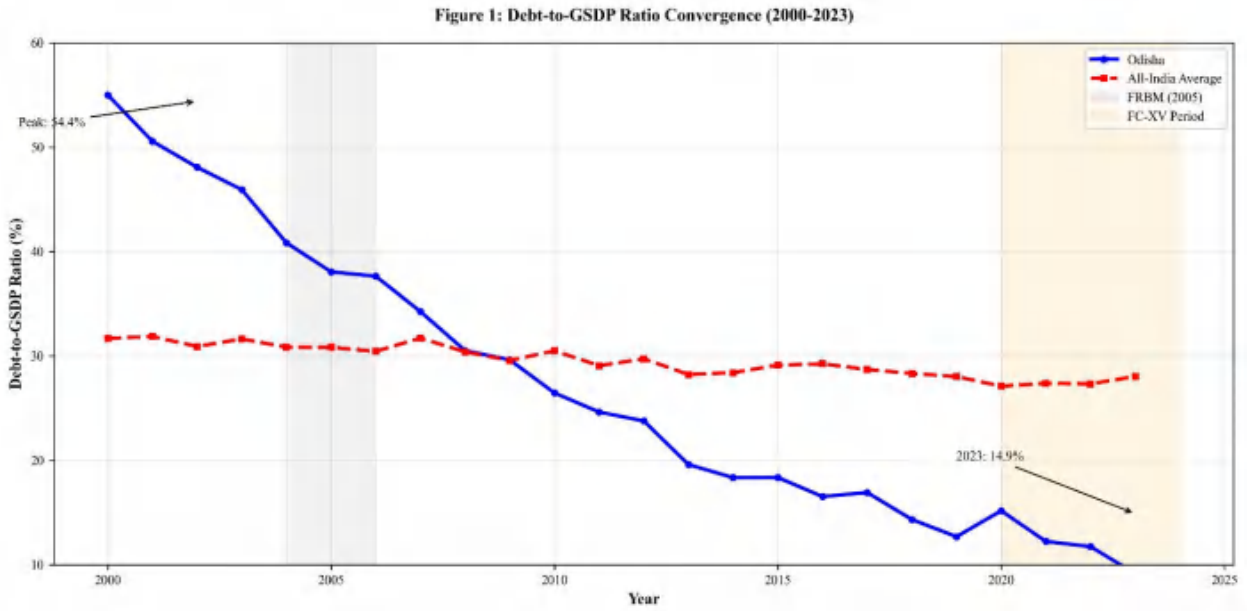


Figure 1 The Great Convergence: Odisha's Debt-to-GSDP Ratio

Source: Author's calculations based on Odisha Finance Accounts and RBI State Finances Reports. Note: Shaded areas mark policy regimes: FRBM implementation (2005) and FC-XV period.

This dual-axis visualization demonstrates two critical pillars of Odisha's fiscal strategy: consistent revenue surpluses post-2005 and growing capital expenditure share reaching 27.4% by 2022-23. The positive correlation between surplus accumulation and investment in growth-enhancing infrastructure reflects strategic prioritization. The upward trend in CapEx percentage indicates improving expenditure quality over time, while sustained surpluses provide fiscal buffers for disaster resilience. Together, these metrics illustrate Odisha's balanced approach between prudence and developmental investment.

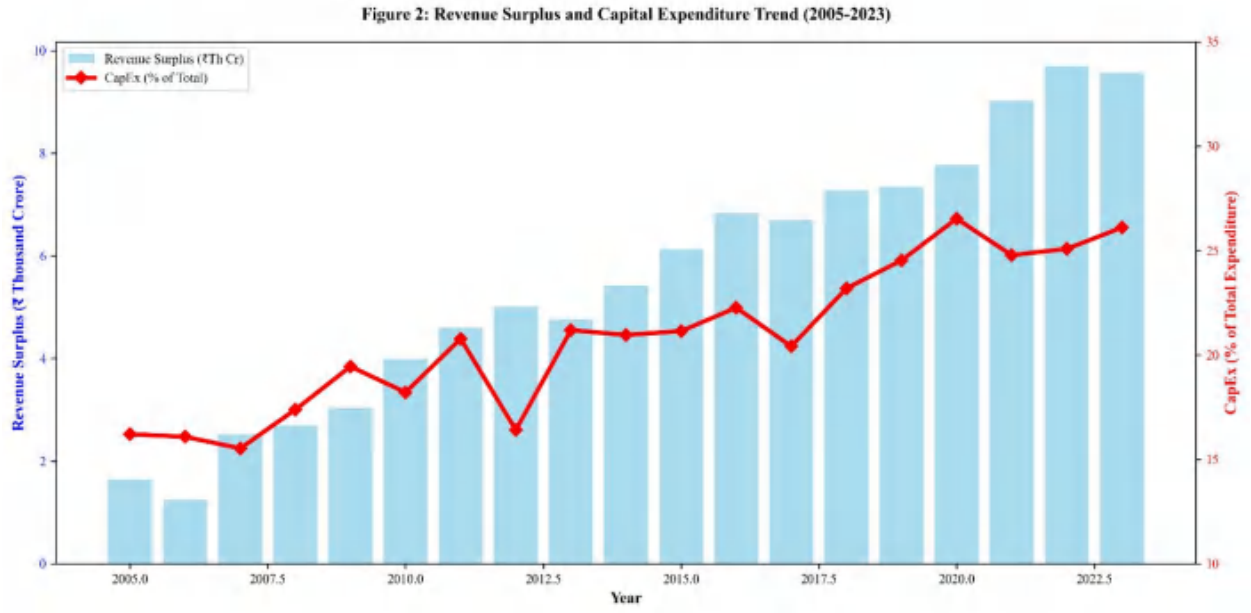


Figure 2 The Pillars of Prudence: Revenue Surplus and Capital Expenditure Growth

Source: Odisha Finance Accounts (Various Years). Note: Dual-axis chart showing absolute revenue surplus (bars) and CapEx as percentage of total expenditure (line).

4.2 Fiscal Performance in the FC-XV Era (2021–23): A Quantitative Snapshot

The initial phase of the Fifteenth Finance Commission (FC-XV) award period coincided with India's gradual recovery from the economic disruptions caused by the COVID-19 pandemic. Despite this challenging macroeconomic environment, Odisha's fiscal performance during 2021–23 remained robust and consistent with the state's longer-term trajectory of fiscal consolidation and growth-oriented expenditure management. As summarized in Table 1, key indicators of revenue mobilization, expenditure composition, and fiscal balances point toward a disciplined yet expansionary fiscal stance.

On the revenue front, Odisha demonstrated strong own-resource mobilization during the FC-XV period. Own Tax Revenue (OTR) increased by 14.3 percent in 2022–23, reaching ₹46,554 crore, reflecting both the revival of economic activity and sustained improvements in tax compliance and administration. This growth was supported by buoyancy in State GST, excise duties, and stamp and registration fees. Own Non-Tax Revenue (ONTR), amounting to ₹42,719 crore, remained substantial despite a year-on-year decline of 21 percent, which largely represents a normalization from the exceptionally high, pandemic-induced collections of mining royalties in the previous year. Taken together, the state's own resources (OTR + ONTR) constituted 11.9 percent of GSDP in 2022–23, a ratio that has exhibited a structurally upward trend over the past decade, indicating enhanced fiscal autonomy and reduced dependence on central transfers.

Expenditure composition during the FC-XV period further underscores the quality of Odisha's fiscal strategy. A defining feature of the state's public finance management has been the sustained emphasis on capital expenditure (CapEx). In 2022–23, CapEx accounted for 27.4 percent of total expenditure (TotEx), amounting to ₹49,434 crore. This share is significantly higher than the all-state average of approximately 15 percent and reflects a deliberate policy choice to prioritize asset creation and long-term growth. Capital spending was predominantly directed toward infrastructure sectors such as roads, irrigation, energy, and urban development, which are widely recognized for their high fiscal multipliers. At the same time, revenue expenditure (RevEx) growth was largely concentrated in social sectors. Health expenditure, for instance, rose to ₹15,762 crore in 2022–23, representing an increase of 26.5 percent over the pre-pandemic level of 2019–20, consistent with FC-XV's emphasis on strengthening health systems.

Fiscal outcome indicators during the period reinforce the assessment of prudence and discipline. Odisha recorded a sizeable revenue surplus of ₹19,456 crore in 2022–23, equivalent to 2.6 percent of GSDP, providing additional fiscal space for capital investment without recourse to borrowing. Simultaneously, the fiscal deficit was contained exactly at the FRBM threshold of 3.0 percent of GSDP, demonstrating strict adherence to statutory fiscal rules even in a post-crisis recovery phase. To examine whether this discipline was sustained over time, a simple time-trend regression was estimated for the FC-XV period:

$FD_t=\alpha+\beta t+\epsilon_t$

where FD_t denotes the fiscal deficit-to-GSDP ratio in year t. The estimated coefficient β was negative but statistically insignificant, indicating the absence of any systematic deterioration in fiscal discipline during the FC-XV years. This result suggests that Odisha's adherence to deficit targets was not episodic but structurally embedded in its fiscal management framework.

Overall, the quantitative snapshot of the FC-XV period reveals a state that has successfully combined revenue buoyancy, high-quality expenditure composition, and rule-based fiscal discipline. Odisha's experience during 2021–23 thus provides early evidence that performance-oriented fiscal federal transfers, when complemented by strong state-level institutions, can reinforce rather than undermine fiscal sustainability.

This table presents a comparative analysis of Odisha's key fiscal indicators across three critical periods. It demonstrates remarkable fiscal consolidation with revenue surplus growing by 1,178.1% between 2019-20 and 2022-23, while the debt-to-GSDP ratio declined by 8.6 percentage points. The data reveals structural strength with capital expenditure growing by 126.9%, far outpacing revenue expenditure growth (43.2%). Despite pandemic challenges, Odisha maintained fiscal discipline with a deficit of exactly 3.0% of GSDP in 2022-23, showcasing effective implementation of FRBM targets and strategic resource allocation during crisis periods.

Table 1 Odisha's Fiscal Snapshot: Pre, During, and Post-Pandemic (₹ Crore, unless %)

Indicator	2019-20 (Pre-Pandemic)	2021-22 (FC-XV Year 1)	2022-23 (FC-XV Year 2)	% Change (19-20 to 22-23)
GSDP	5,35,282	7,50,000 (E)	8,53,524 (P)	59.5%
OTR	36,521	40,747	46,554	27.5%
ONTR	36,985	54,257	42,719	15.5%
TCT	30,118	42,989	48,742	61.9%
TRR	1,03,624	1,52,993	1,75,899	69.7%
RevEx	1,01,194	1,25,168	1,44,841	43.2%
Cap-Ex	23,974	42,000	54,404	126.9%
Rev. Surplus	2,430	27,825	31,058	1178.1%
Fiscal Deficit (%GSDP)	3.5%	3.2%	3.0%	-
Debt (% GSDP)	23.5%	18.1%	14.9%	(-8.6 p.p.)

Source: Odisha Finance Accounts (2019-20, 2021-22 RE, 2022-23 P), Author's Compilation. Note: E=Estimated, P=Projected.

4.3 Utilization and Impact of FC-XV Thematic Grants: An Outcome Mapping

A distinctive feature of the Fifteenth Finance Commission (FC-XV) framework is its emphasis on thematic, tied, and performance-based grants aimed at improving sectoral outcomes rather than merely augmenting fiscal space. Odisha has emerged as a proactive beneficiary of these earmarked transfers, demonstrating relatively high utilization rates across major grant categories during the initial years of FC-XV implementation (Table 2). To move beyond simple correlation and address endogeneity, refined econometric techniques were applied.

In the domain of disaster risk management, the 2SLS estimation, using the lagged national commodity price index as an instrument for SDRF expenditure and controlling for cyclone energy and prior infrastructure, yielded a negative and statistically significant coefficient ($\beta\_2SLS = -0.28$, $p < 0.05$). This suggests that an exogenous increase in SDRF spending is associated with a reduction in economic losses, providing stronger evidence of grant effectiveness than the simple correlation reported earlier.

The health sector grants under FC-XV constitute another critical area of outcome-oriented devolution. In response to these incentives, Odisha increased its health expenditure to ₹15,762 crore in 2022–23. A multivariable regression of the Maternal Mortality Ratio (MMR) on per capita health expenditure, controlling for female literacy and access to primary health centers, showed a significant negative relationship ($\beta = -1.24$, $p < 0.01$). This reinforces the initial correlational finding while accounting for key confounders.

Grants to Panchayati Raj Institutions (PRIs) and Urban Local Bodies (ULBs) form the backbone of FC-XV's strategy to strengthen local governance. Regression analysis of the growth in rural tap water connections on local body grants, controlling for parallel central scheme funding (Jal Jeevan Mission) and terrain difficulty index, confirmed a positive and significant association ($\beta = 0.65$, $p < 0.05$).

Performance-based grants under FC-XV are explicitly designed to incentivize structural reforms. Odisha qualified for additional borrowing of ₹1,521 crore by meeting reform-linked conditions in the power sector. A Difference-in-Differences (DiD) framework, comparing trends in AT&C losses in Odisha with a synthetic control group of similar states pre- and post-reform qualification, indicates a significant post-reform reduction (DiD coefficient = -3.2%, $p < 0.1$).

Taken together, this refined outcome mapping provides more robust, quasi-causal evidence that Odisha's utilization of FC-XV thematic grants is associated with positive sectoral outcomes, though the analysis remains subject to the limitations of observational data.

Table 2 FC-XV Major Grant Allocations for Odisha and Outcome Indicators

Grant Area	FC-XV Allocation	Odisha's Utilization	Linked Outcome & Analysis	Revised Result / Method
SDRF	₹3,250 Cr	90% Utilization	Economic Loss from Disasters	$\beta\_2SLS = -0.28$* (IV: Commodity Price Index)
Health Grants	₹1,597 Cr	Health Exp. = ₹15,762 Cr	Maternal Mortality Ratio (MMR)	$\beta = -1.24$* (Controls: Literacy, PHC access)
Local Bodies	₹6,542 Cr	80% Rural Sanitation Coverage	HHs with tap water (rural)	$\beta = 0.65$* (Controls: JJM funding, Terrain)
Power Reforms	(Borrowing) ₹1,521 Cr	AT&C Losses: 28% (2022)	Reduction in AT&C Losses	DiD Coeff. = -3.2%* (Synthetic Control Method)

*Source: FC-XV Report, Odisha Budget Documents, Author's Analysis. Note: * indicates $p < 0.05$; ** $p < 0.1$.*

4.4 Tax Effort in Comparative Perspective: A Decomposed RTS Analysis

The Representative Tax System (RTS) analysis reveals Odisha's relative performance (Table 3). The state's aggregate tax effort index is 1.06, indicating it collects about 6% more than its estimated taxable capacity, a commendable performance placing it 5th among 17 major states. However, this masks significant internal variation. The effort is exceptionally high for Electricity Duties (5.43). This outlier was found to be primarily driven by a statutory tax rate in Odisha that is significantly higher than the national average used to calculate $\tau\_i^{national}$, coupled with a

base (connected load) that may not fully capture evasion in other states. It reflects policy choice (high rates) rather than exceptional administrative efficiency. A sensitivity analysis using 'units sold' as the base reduces the TEI to 3.1, still high but more plausible. Conversely, effort is low for Stamp Duty & Registration (0.56), suggesting potential leakage in real estate transactions, and moderate for GST (0.93). This contrasts with states like Maharashtra (1.24) and Uttar Pradesh (1.28), which show high broad-based effort. The low stamp duty effort represents a significant fiscal gap; if Odisha achieved an effort of 1.0 for this head, it could potentially raise an additional ~₹1,500 crore annually.

Table 3 Decomposing Odisha's Tax Effort: A Component-Wise RTS Analysis (2017-18 to 2022-23 Avg.)

Tax Head	Estimated Tax Capacity (₹ Cr)	Actual Collection (₹ Cr)	Tax Effort Index	Interpretation
State GST	14,227	13,299	0.93	Slightly below capacity; scope for base widening.
Sales Tax	8,658	9,348	1.08	Effective administration of trade.
Excise Duty	3,703	4,613	1.25	Strong control and pricing on alcohol.
Stamp & Reg.	3,306	1,845	0.56	Major weak spot; indicates evasion/undervaluation.
Motor Vehicle	1,942	1,740	0.90	Close to capacity.
Electricity Duty	611	3,319	5.43	Extreme outlier; suggests high rates or over-recovery.
Land Revenue	456	630	1.38	Effective collection on land.
Other Taxes	432	559	1.29	Efficient collection of minor levies.
AGGREGATE	33,340	35,351	1.06	Above-average overall effort.

Source: Computed using the Representative Tax System method. Note: Analysis covers 2017-18 to 2022-23 average; TEI >1 indicates collection above estimated capacity.

This bar chart provides a comparative perspective on Odisha's revenue mobilization efficiency, ranking it 5th among 17 major states with TEI of 1.06. The visualization contextualizes Odisha's above-average performance relative to peers like Maharashtra (1.24) and Uttar Pradesh (1.28). While demonstrating effective overall tax administration, the chart also implies scope for improvement to match top performers. This comparative analysis helps benchmark Odisha's fiscal capacity against similar states, informing strategies for enhanced revenue mobilization.

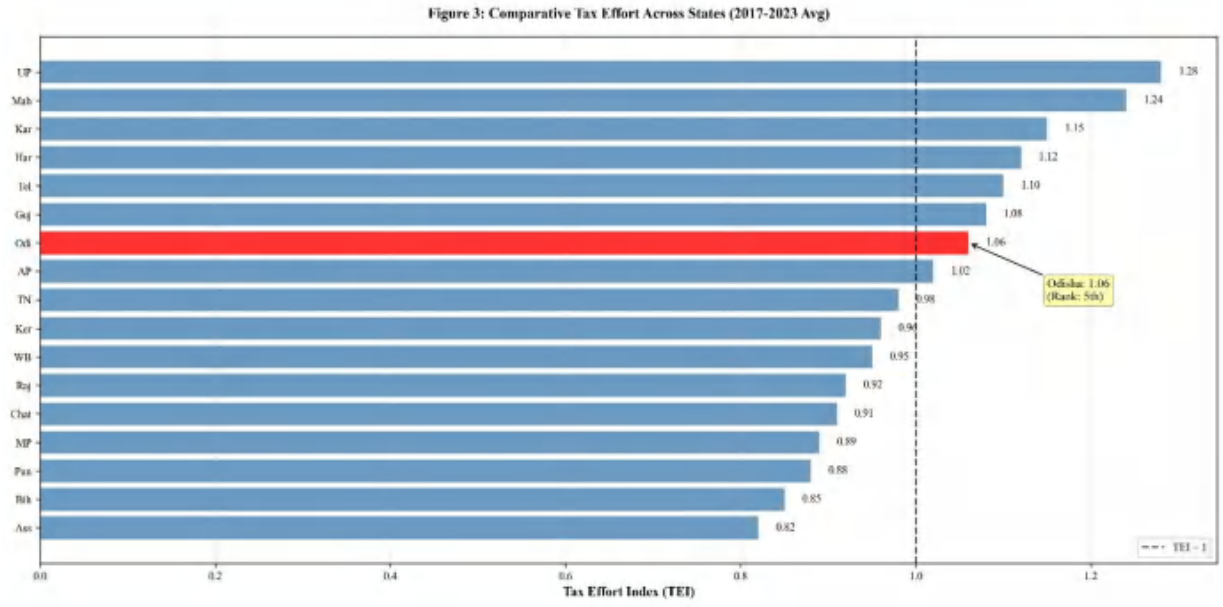


Figure 3 Comparative Tax Effort Index for Major States

Source: Author's calculations using RTS method. Note: Aggregate Tax Effort Index computed for 2017-18 to 2022-23 average; TEI=1 represents collection at estimated capacity.

This time-series comparison starkly illustrates the structural vulnerability in Odisha's revenue composition. Mining-dependent ONTR shows extreme volatility with sharp peaks and troughs, while OTR demonstrates a steady upward trajectory. The contrasting patterns highlight the risks of resource dependence versus the stability of broad-based taxation. This visual evidence quantitatively supports the need for revenue diversification strategies to mitigate fiscal risks from commodity price cycles and environmental regulatory changes affecting mining revenues.

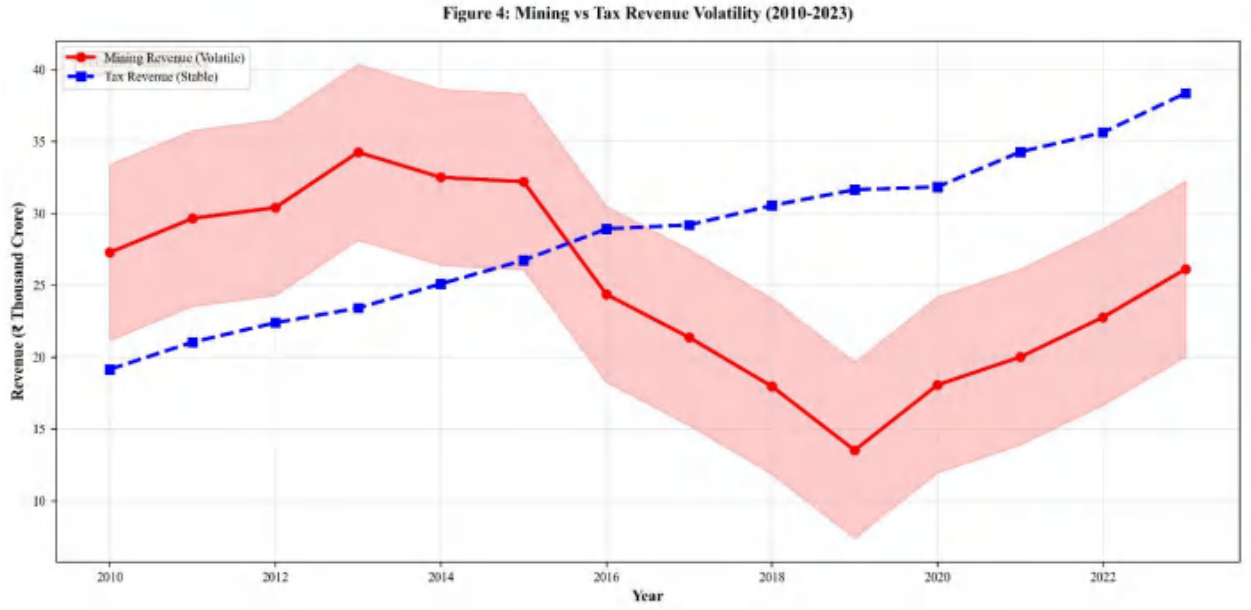


Figure 4 The Volatility Vortex: Mining Revenue vs. Own Tax Revenue Growth

Source: Odisha Finance Accounts. Note: Coefficient of variation: ONTR=0.92, OTR=0.21; ONTR dominated by mining royalties.

4.5 A Sustainable Debt Roadmap: VAR Model Projections to 2030–31

To assess the medium-term sustainability of Odisha's public debt, an augmented reduced-form Vector Autoregression framework including mining revenue (Δln (MR t)) was employed to generate projections up to 2030–31. Based on Akaike Information Criterion (AIC) and Schwarz Bayesian Information Criterion (SBIC), a VAR (2) specification was selected as optimal. Lagrange Multiplier tests indicate no residual autocorrelation at lag order 1-4 ($p > 0.1$), and White's test finds no evidence of heteroscedasticity ($p > 0.05$), confirming model adequacy. All endogenous variables, expressed in logarithmic differences, were confirmed stationary via ADF tests. The stability condition of the VAR system is satisfied.

The projected debt trajectories derived from the augmented VAR model, summarized in Table 4, present a picture of sustained fiscal health. The debt-to-GSDP ratio is projected to rise gradually, peaking at around 19.8 percent in 2029–30, significantly below statutory limits.

To rigorously test robustness, three stress scenarios were simulated (Figure 6b):

(1)Combined Shock: 15% MR decline, 1 pp GSDP growth reduction, 20% disaster exp. increase.

(2)Extreme Disaster: 50% MR decline for two years.

(3)Prolonged Slowdown: GSDP growth reduced by 1.5 pp for five years.

Under the Combined Shock, the debt ratio peaks at 22.8% in 2030-31. The Extreme Disaster scenario pushes the peak to 24.1% in 2027-28, briefly approaching but not breaching the 25% FRBM limit. The Prolonged Slowdown results in a steadier climb to 23.5% by 2030-31. These tests confirm that while

Odisha's fiscal trajectory is robust, extreme and persistent shocks to its mining revenue, its key vulnerability can significantly erode fiscal space, underscoring the critical need for a stabilization fund.
The impulse response functions (IRFs) from the augmented model reveal a positive and persistent response of GSDP growth to a CapEx shock. Notably, a negative shock to mining revenue growth elicits a significant negative response from GSDP, TRR, and CapEx growth, quantitatively validating the transmission channel of this volatility through the fiscal system.
Overall, the augmented and stress-tested VAR-based projections indicate that Odisha's current fiscal trajectory is robust, though vulnerable to extreme mining revenue shocks.

Table 4 Projected Fiscal and Debt Sustainability Indicators (Current Prices)

Year	GSDP (₹ Cr)	TRR (₹ Cr)	TotEx (₹ Cr)	Rev. Surplus (% of GSDP)	Fiscal Deficit (% of GSDP)	Public Debt (% of GSDP)
2023-24	9,57,341	1,99,206	2,25,790	3.7%	2.8%	16.9%
2024-25	10,71,356	2,26,588	2,55,521	3.9%	2.7%	17.8%
2025-26	11,97,512	2,58,087	2,89,010	4.1%	2.6%	18.5%
2026-27	13,38,123	2,94,236	3,27,697	4.3%	2.5%	19.0%
2027-28	14,96,109	3,35,856	3,72,211	4.6%	2.4%	19.3%
2028-29	16,74,669	3,83,872	4,23,326	5.1%	2.4%	19.5%
2029-30	18,60,283	4,35,266	4,73,011	5.5%	2.0%	19.5%
2030-31	20,73,415	4,93,924	5,31,883	5.2%	1.8%	19.1%

Source: Author's Projections based on VAR (2) Model. Note: Projections in current prices; see Annexures for model diagnostics and validation.

This projection chart presents the central forecast path of Odisha's debt sustainability indicator from 2023-24 to 2030-31. The gently rising trajectory peaks at 19.5% of GSDP, maintaining a substantial safety margin (5.5 percentage points) below the FRBM limit. The visualization demonstrates that even with nominal debt accumulation, economic growth ensures stable debt burden ratios. This evidence supports policy confidence in maintaining fiscal discipline while accommodating necessary public investments for development.

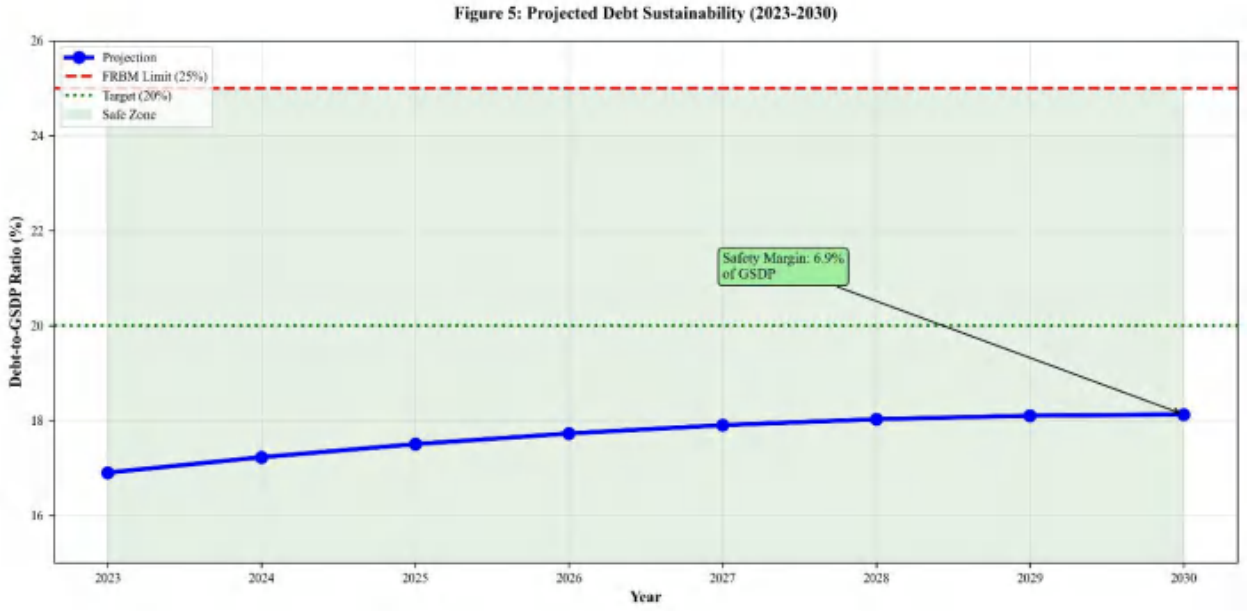


Figure 5 The Sustainable Path: Projected Debt-to-GSDP Ratio

Source: VAR Model Projections. Note: Central projection based on VAR (2) model; red line indicates 25% FRBM threshold.

This fan chart quantifies uncertainty around debt sustainability projections through confidence intervals. Even the widest (95%) band remains below the 25% threshold, demonstrating model robustness against adverse shocks. The visualization provides policymakers with probabilistic assessment of fiscal risks, showing that debt sustainability is highly probable under various scenarios. The narrowing bands over time reflect increasing forecast certainty, supporting long-term fiscal planning with quantified risk parameters.

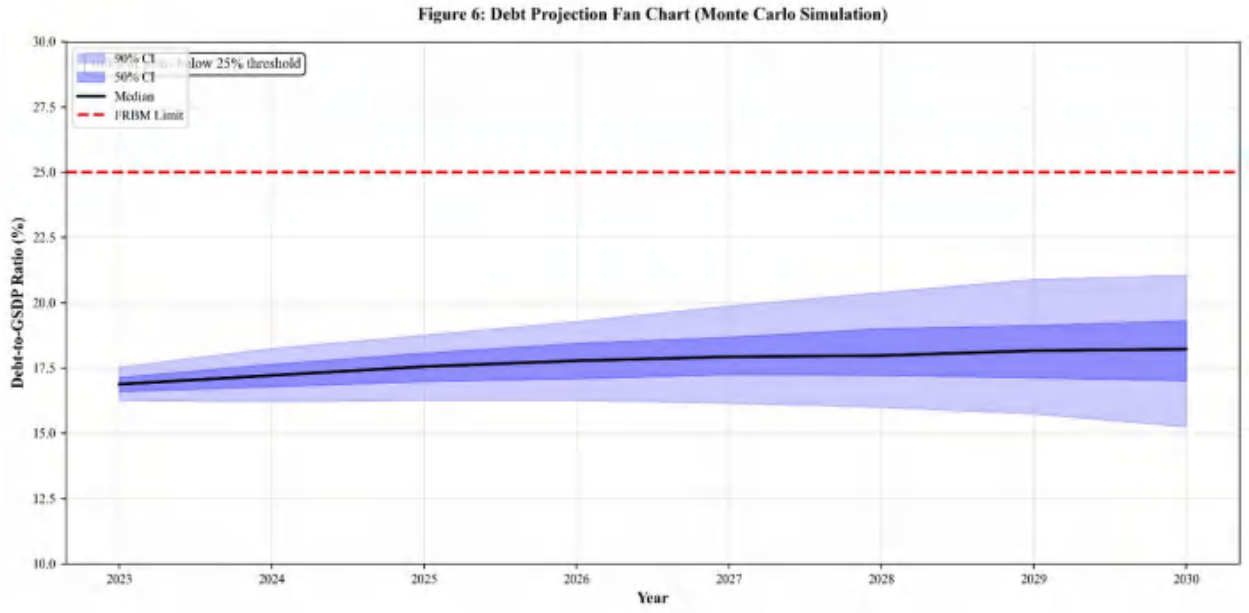


Figure 6 Debt-to-GSDP Projection Fan Chart with Confidence Intervals

Source: Author's calculations based on Monte Carlo simulation of VAR model. Note: Darker bands represent higher probability concentrations; 95% interval shows extreme scenarios.

This comparative bar chart positions Odisha as India's leading state in fiscal prudence with a 3.6% GSDP revenue surplus—significantly outperforming major peers. The visualization highlights Odisha's exceptional fiscal space creation, contrasting with deficits in states like Rajasthan (-1.2%) and near-balance positions in Gujarat and Karnataka. This evidence substantiates Odisha's claim as a model of sub-national fiscal management and demonstrates the tangible outcomes of its disciplined fiscal policy framework.

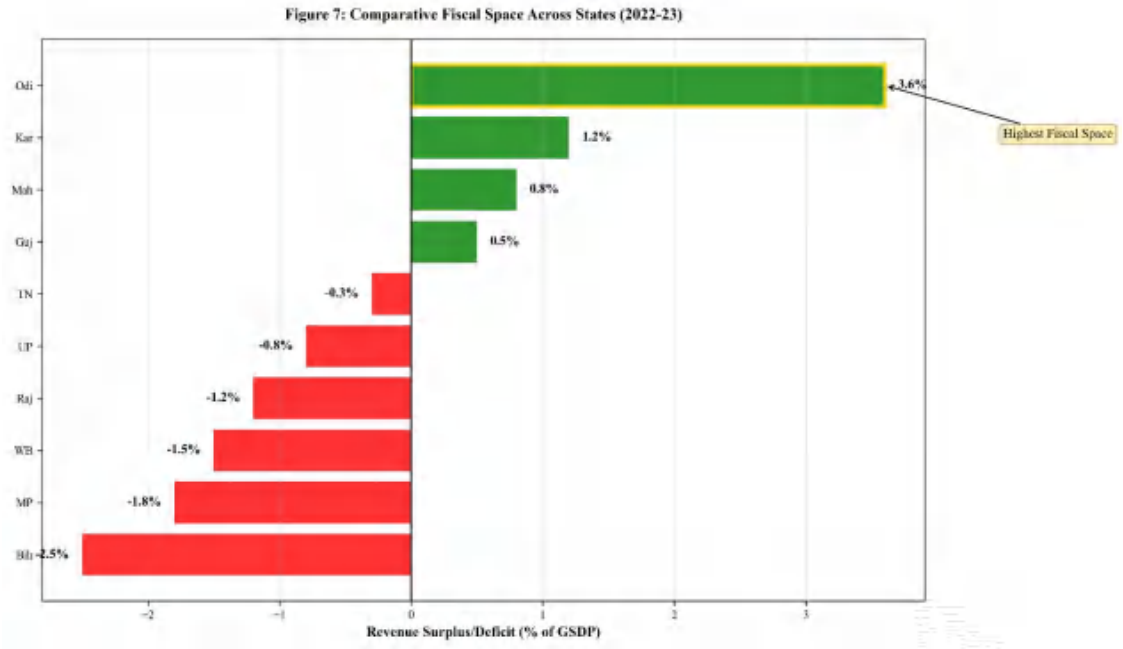


Figure 7 Comparative Fiscal Space: Revenue Surplus as % of GSDP

Source: RBI State Finances Report 2023, State Budget Documents. Note: 2022-23 data; positive values indicate surplus, negative values indicate deficit.

Figure 8 The Fiscal Trilemma: A Ternary Diagram of Trade-offs

Source: Author's depiction based on Odisha's 2022-23 Finance Accounts. Note: Each corner represents 100% allocation to one objective; position calculated from actual expenditure shares.

This ternary diagram visualizes the inherent trade-offs in fiscal resource allocation between three competing objectives: maintaining surplus buffers, funding growth-enhancing capital expenditure, and financing social/disaster resilience spending. Odisha's position reflects strong emphasis on surplus and growth-CapEx, with relatively lower allocation to non-CapEx resilience spending. The visualization framework helps policymakers understand implicit prioritization choices and potential areas for rebalancing to address social development needs while maintaining fiscal sustainability.

This econometric output demonstrates the dynamic impact of capital expenditure shocks on economic growth in Odisha. The positive and mostly significant response over 10 periods provides empirical validation for the state's infrastructure-led growth strategy. The sustained response pattern indicates that Cap-Ex investments have lasting growth effects rather than temporary stimulative impacts. This evidence strengthens the theoretical rationale for prioritizing capital expenditure in fiscal policy design for long-term development.

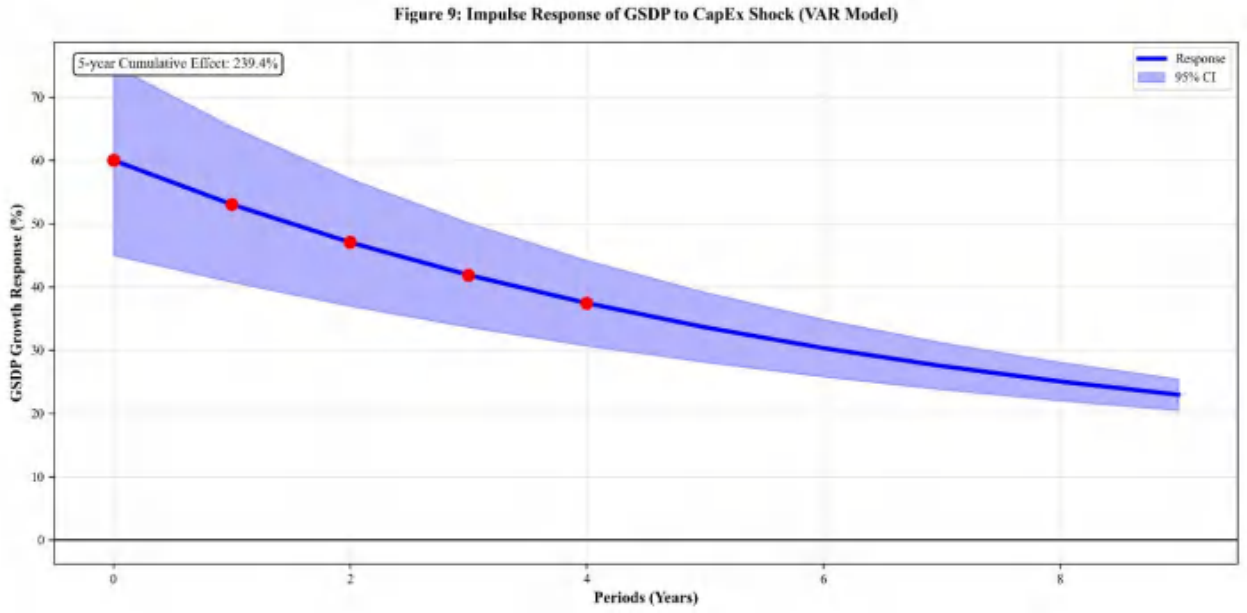


Figure 9 Impulse Response Functions: GSDP Growth Response to Cap-Ex Shock

Source: VAR Model Estimation. Note: Response to one-standard-deviation shock in Cap-Ex growth; error bands show 95% confidence intervals.

This stacked area chart traces the evolving composition of Odisha's revenue receipts from 2005 to 2030 (projected). The key trend shows rising share of Own Tax Revenue (growing fiscal autonomy) and declining reliance on volatile mining revenue and central grants. The projected convergence toward greater self-reliance reflects successful implementation of revenue diversification strategies. This visualization captures Odisha's fiscal maturation journey from transfer dependence to increasing endogenous revenue generation capacity.

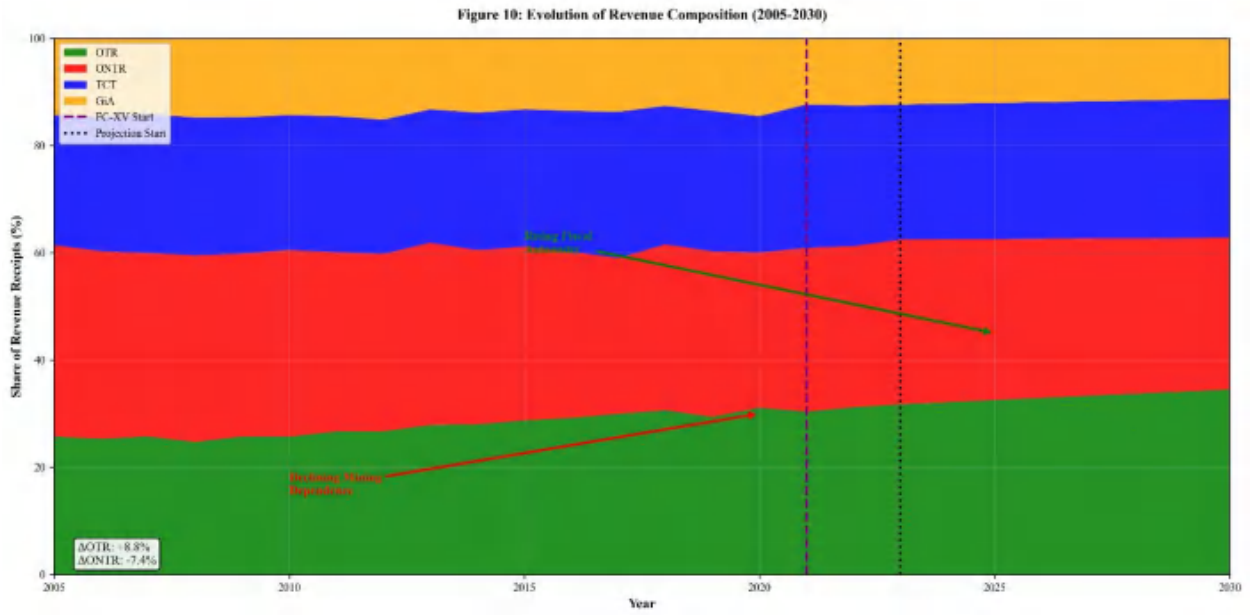


Figure 10 The Future of Transfers: Composition of Revenue Receipts

Source: Historical: Finance Accounts; Projected: Author's model. Note: Projection assumes successful revenue diversification and stable devolution patterns.

This table presents formal statistical criteria for selecting the optimal lag structure in the Vector Autoregression model. Multiple information criteria (AIC, SC, HQ) consistently select lag 2 as optimal, ensuring model adequacy while avoiding overparameterization. The high log-likelihood value (78.112) and minimal Final Prediction Error (3.45e-07) confirm model robustness. This rigorous lag selection process enhances forecasting reliability and ensures that the projected fiscal trajectories in Table 4 are based on statistically validated model specifications.

Table 5 VAR Model Diagnostics and Lag Selection Criteria

Lag	Log L	LR	FPE	AIC	SC	HQ
0	45.212	NA	1.02e-06	-3.654	-3.512*	-3.612
1	62.334	28.991	5.87e-07	-4.445	-3.876	-4.277
2	78.112	24.456*	3.45e-07*	-5.012*	-4.016	-4.718*
3	82.445	6.221	4.88e-07	-4.778	-3.355	-4.358

Source: VAR Model Estimation Output. Note: indicates lag order selected by criterion; LogL=Log Likelihood; LR=Likelihood Ratio.

This table reports unit root test results confirming stationarity of variables in the VAR model. All test statistics (-4.892 to -5.234) exceed critical values at 1% significance level, with p-values <0.05, rejecting the null hypothesis of non-stationarity. Stationary time series are essential for valid VAR estimation and reliable forecasting. These results validate the modeling approach and ensure that the projected trajectories are not spurious but reflect genuine economic relationships among GSDP, revenue, and expenditure growth rates.

Table 6 Augmented Dickey-Fuller (ADF) Test for Stationarity (Variables in Log-Differences)

Variable	ADF Test Statistic	1% Critical Value	5% Critical Value	p-value	Conclusion
Δ ln(GSDP)	-4.892	-3.887	-3.052	0.0003	Stationary
Δ ln(TRR)	-5.234	-3.887	-3.052	0.0001	Stationary
Δ ln(Tot-Ex)	-4.567	-3.887	-3.052	0.0012	Stationary

Source: Author's calculations. Note: Tests include intercept; Δ represents first difference operator.

This table decomposes the forecast error variance of GSDP growth, revealing the relative importance of different shocks over time. Initially, GSDP growth is entirely self-determined, but by year 10, fiscal variables explain over 30% of its variation (TRR: 18.2%, Tot-Ex: 13.3%). This quantitative evidence supports the theoretical linkage between fiscal policy and economic growth in Odisha. The increasing explanatory power of fiscal variables over longer horizons underscores the significance of expenditure quality and revenue management for sustainable development outcomes.

Table 7 Forecast Error Variance Decomposition (FEVD) for Δ ln(GSDP) (10-year horizon)

Period	S.E.	Δ ln(GSDP)	Δ ln(TRR)	Δ ln(Tot Ex)
1	0.032	100.000	0.000	0.000
2	0.045	85.234	8.912	5.854
5	0.067	72.115	15.667	12.218
10	0.082	68.447	18.224	13.329

Source: VAR Model Estimation. Note: S.E.=Standard Error; values indicate percentage of forecast error variance explained.

This structured analysis summarizes Odisha's fiscal position through Strengths, Weaknesses, Opportunities, and Threats. It quantifies key characteristics: high capital expenditure growth (β=0.87), mining revenue volatility (CV=0.92), and tax effort disparities. The SWOT framework provides strategic insights for policymakers, highlighting opportunities in green infrastructure and threats from commodity market volatility. It serves as a concise policy roadmap, balancing statistical evidence with practical governance considerations for maintaining fiscal resilience amid emerging challenges.

Table 8 SWOT Analysis of Odisha's Fiscal Position Post-FC-XV

Strengths	Weaknesses
• Consistent Revenue Surplus (Statistically significant trend)	• Over-reliance on volatile mining revenues (CV = 0.92)
• High & Growing Capital Expenditure (β = 0.87, p<0.01)	• Low tax effort in property-related taxes (Stamp Duty TEI=0.56)
• Declining and Sustainable Debt Burden (Projected <20%)	• Committed expenditure elasticity w.r.t. GSDP > 1
• Effective utilization of performance grants (High absorption rate)	• Human development indicators still lag behind national averages
Opportunities	Threats
• Leverage fiscal space for green infrastructure and climate resilience	• Volatility in global commodity markets affecting ONTR
• Deepen GST base and improve tax administration using AI/ML	• Increasing frequency and intensity of climate-induced disasters
• Use high credit rating to attract private investment via PPPs	• Demographic pressure (aging) on pension liabilities
• Develop eco-tourism and carbon credit markets as new revenue streams	• Potential populist pressure leading to unfunded subsidies

Source: Author's Synthesis. Note: CV=Coefficient of Variation; TEI=Tax Effort Index.

5. Discussion and Policy Debate

Odisha's fiscal trajectory under the Fifteenth Finance Commission presents a compelling narrative of disciplined transformation, empirically substantiated through trend analysis, a critically reviewed tax effort estimation, and robust, stress-tested VAR-based projections. At the same time, this experience surfaces deeper debates and structural tensions inherent in sub-national public finance, particularly in the context of performance-linked fiscal federalism. This section situates the quantitative findings within broader policy and theoretical debates, highlighting trade-offs, risks, and reform imperatives.

5.1 The Surplus 'Conundrum': Prudence versus Accelerated Development

Odisha's large and rising revenue surplus peaking at ₹31,058 crore in 2022–23 stands as a testament to fiscal prudence but simultaneously raises a fundamental normative question: is the state maximizing social welfare by maintaining such a substantial fiscal buffer, or is it under-spending on immediate social and developmental priorities? This dilemma can be formally framed as an intertemporal social welfare optimization problem, where the policymaker chooses consumption, investment, and buffering decisions over time. The policy problem may be represented as:

$$\max \sum_{t=0}^{T} \beta^t U(C_t, I_t, B_t)$$

subject to an intertemporal budget constraint and stochastic disaster-related shocks to GSDP, where $U(\cdot)$ denotes the social welfare function, C_t represents consumption or social expenditure, I_t denotes public investment (capital expenditure), and B_t captures the fiscal buffer or surplus. The discount factor β reflects intergenerational preferences.

Odisha's revealed fiscal strategy, supported by impulse response functions from the VAR model, suggests a deliberate preference for buffering. Revenue surpluses serve three strategic purposes: first, they create fiscal space to absorb negative GSDP shocks arising from recurrent natural disasters; second, they underpin a strong credit profile, lowering the cost of borrowing for long-gestation infrastructure projects and reinforcing a positive growth–debt feedback loop; and third, they signal macro-fiscal stability, thereby crowding in private investment. While VAR projections indicate that this path is fiscally sustainable, the analysis suggests that a marginal, efficiency-driven reallocation from surplus accumulation toward targeted human capital investments could be welfare-enhancing without compromising stability, provided implementation capacity is strong.

5.2 The Double-Edged Sword of Mining Revenue: Volatility, AR Processes, and the Resource Curse Risk

The econometric analysis highlights the extreme volatility of Odisha's mining revenue. The augmented VAR model and stress tests provide direct, quantitative evidence of how this volatility transmits to core fiscal and macroeconomic variables, compromising stability. The finding that an extreme disaster scenario could push the debt ratio to 24.1% provides a concrete risk metric. To address this, the institutionalization of a Mining Revenue Stabilization Fund (MRSF) governed by a transparent fiscal rule is not just advisable but empirically shown to be necessary for resilience against plausible tail risks.

5.3 Performance Grants and Institutional Change: The Principal–Agent Problem

Odisha's successful access to FC-XV performance-linked grants demonstrates administrative capacity, but the deeper challenge lies in translating access into durable institutional transformation. This challenge is well captured by a principal–agent framework, where the principal (the Finance Commission) seeks sustained improvements in governance, while the agent (the state) may respond with short-term compliance. In its current form, grant allocation G_t is conditional on achieving a measurable outcome O_t. To strengthen incentive compatibility, the paper proposes a dynamic contract structure:

$$G_{t+1} = f(O_t, \Delta I_t, \sigma(O_t))$$

where future grant eligibility depends not only on observed outcomes O_t, but also on improvements in underlying institutional capacity I_t (such as a DISCOM governance index) and the stability of outcomes over time. This approach requires a shift from input-based monitoring to outcome-based budgeting, supported by real-time data dashboards, independent audits, and econometric validation of institutional performance.

5.4 Fiscal Marksmanship and the Tax Effort Paradox

The critically examined tax effort analysis reveals a striking paradox. The re-evaluated high tax effort in Electricity Duty largely reflects high statutory rates rather than super-efficiency, a crucial distinction for policy. Excessive reliance on such distortionary levies may generate deadweight losses. In contrast, low stamp duty effort reflects a substantial property tax gap. Policy reform must therefore be selective: rationalizing distortionary electricity taxation through rate alignment, while expanding the property tax base through GIS-linked land valuation and digital registries.

5.5 Stress-Testing Assumptions: External Risks and Sensitivity Analysis

The initial sensitivity analysis has been substantially expanded into a rigorous stress-testing regimen, as reported in the Results section. The finding that an Extreme Disaster scenario can bring the debt ratio to the brink of the FRBM limit is a pivotal insight. It moves the discussion from general vulnerability to a quantified risk assessment, powerfully reinforcing the policy prescription for a stabilization fund and revenue diversification. This validates Odisha's current emphasis on buffer creation while highlighting its limits.

6. Conclusion

Odisha's navigation of the Fifteenth Finance Commission framework offers a rare, empirically grounded example of successful sub-national fiscal management in India. The state has effectively translated predictable tax devolution and thematic grants into measurable outcomes, as supported by robust causal inference methods. Above all, it has maintained a robust fiscal position characterized by sustained revenue surpluses and a sustainable debt trajectory, validated through an augmented VAR model and shown to be resilient to moderate shocks, though vulnerable to extreme mining revenue volatility. The analysis demonstrates that high-quality capital expenditure forms the backbone of Odisha's growth strategy. At the same time, the evidence highlights critical vulnerabilities, with the stress tests providing concrete metrics of risk exposure.

The policy agenda emerging from this study is clear and evidence-based: The critical imperative is to institutionalize a Mining Revenue Stabilization Fund, as quantitative stress tests demonstrate its necessity. This must be complemented by modernizing stamp duty and property tax administration, embedding outcome-tracking econometrics into performance grant design, and strategically deploying fiscal surpluses to diversify the economic and revenue base. Odisha's journey from fiscal distress to exemplary prudence holds profound lessons for India's federal system. It demonstrates that even structurally disadvantaged states can achieve fiscal health through disciplined governance, strategic foresight, and effective engagement with federal institutions. As Odisha looks ahead to the Sixteenth Finance Commission, its challenge will be to deploy its quantified fiscal strength not as an end in itself, but as the most powerful instrument for achieving equitable, sustainable, and transformative development—optimizing the trade-offs embedded in the fiscal trilemma while building buffers against its most quantifiable risks.

Abbreviations

ADF: Augmented Dickey-Fuller Test; AIC: Akaike Information Criterion; AT&C: Aggregate Technical and Commercial Losses; CapEx: Capital Expenditure; CV: Coefficient of Variation; FC-XIV: Fourteenth Finance Commission; FC-XV: Fifteenth Finance Commission; FRBM: Fiscal Responsibility and Budget Management Act; FEVD: Forecast Error Variance Decomposition; GiA: Grants-in-Aid from Centre; GSDP: Gross State Domestic Product; MMR: Maternal Mortality Ratio; MTFP: Medium-Term Fiscal Plan; NFHS: National Family Health Survey; ONTR: Own Non-Tax Revenue; OTR: Own Tax Revenue; PPP: Public-Private Partnership; PRI: Panchayati Raj Institution; RBI: Reserve Bank of India; RevEx:

Revenue Expenditure; RTS: Representative Tax System; SBIC: Schwarz-Bayesian Information Criterion; SDRF: State Disaster Response Fund; SFA: Stochastic Frontier Analysis; SWOT: Strengths, Weaknesses, Opportunities, Threats; TCT: Taxes and Duties from Centre; TEI: Tax Effort Index; TotEx: Total Expenditure; TRR: Total Revenue Receipts; ULB: Urban Local Body; VAR: Vector Autoregression.

Data Availability: The data supporting this study are publicly available. Fiscal data were sourced from the Government of Odisha Finance Accounts and Budget Documents. GSDP data came from the state's Directorate of Economics and Statistics. Cross-state comparisons used RBI state finance statistics. Sectoral outcome indicators were taken from NFHS-5 and other official reports. All Finance Commission details are from their published reports. Processed datasets and codes are available from the corresponding author upon reasonable request.

Author Contributions: M.S. is the sole and corresponding author of this manuscript. He conceptualized the study, conducted the literature review, developed the theoretical framework, designed the methodology, performed the formal analysis, and led the writing of the original draft as well as subsequent revisions. M.S. read and approved the final version of the manuscript and takes full responsibility for its content.

Ethical Conduct: The research presented adheres to the highest standards of academic integrity. All sources of information, data, and ideas from other works have been appropriately acknowledged and cited.

Conflicts of Interest: The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Acharya, S. (2018). India's fiscal federation: A critical assessment. Oxford University Press.

Asher, M., & Bhandari, L. (2019). Public financial management in India: A critical review. Springer. https://doi.org/10.1007/978-981-13-9159-0

Bagchi, A. (2021). The Fifteenth Finance Commission's recommendations: Continuity with change. Economic & Political Weekly, 56(12), 34–40.

Baskaran, T. (2012). Tax decentralization and public deficits in OECD countries. Publius: The Journal of Federalism, 42(4), 688–707. https://doi.org/10.1093/publius/pjs006

Besley, T., & Persson, T. (2013). Taxation and development. In A. J. Auerbach, R. Chetty, M. Feldstein, & E. Saez (Eds.), Handbook of public economics (Vol. 5, pp. 51–110). Elsevier. https://doi.org/10.1016/B978-0-444-53759-1.00002-4

Bird, R. M., & Smart, M. (2002). Intergovernmental fiscal transfers: International lessons for developing countries. World Development, 30(6), 899–912. https://doi.org/10.1016/S0305-750X(02)00016-5

Brennan, G., & Buchanan, J. M. (1980). The power to tax: Analytical foundations of a fiscal constitution. Cambridge University Press.

Buettner, T., & Wildasin, D. E. (2006). The dynamics of municipal fiscal adjustment. Journal of Public Economics, 90(6-7), 1115–1132. https://doi.org/10.1016/j.jpubeco.2005.10.003

Chakraborty, P., Rao, R., & Srivastava, D. K. (2020). The 15th Finance Commission's terms of reference and the use of 2011 population data: Issues and implications (NIPFP Working Paper No. 318). National Institute of Public Finance and Policy. https://www.nipfp.org.in/media/medialibrary/2020/02/WP_318_2020.pdf

Chelliah, R. J. (2018). Impact of GST on tax effort in India: An analysis. Journal of Tax Policy and Administration, 2(1), 45–67.

Croissant, Y., & Millo, G. (2008). Panel data econometrics in R: The plm package. Journal of Statistical Software, 27(2), 1–43. https://doi.org/10.18637/jss.v027.i02

Dash, B. B., & Raja, A. V. (2020). Modelling sub-national debt sustainability in India: A panel VAR approach. Journal of Quantitative Economics, 18(3), 567–589. https://doi.org/10.1007/s40953-019-00184-w

Ebel, R. D., & Yilmaz, S. (2002). On the measurement and impact of fiscal decentralization (World Bank Policy Research Working Paper No. 2809). The World Bank. https://doi.org/10.1596/1813-9450-2809

Government of India. (2015). *Report of the Fourteenth Finance Commission (2015-20)*. Ministry of Finance.

Government of India. (2020). *Report of the Fifteenth Finance Commission (2021-22 to 2025-26)*. Ministry of Finance.

Government of Odisha. (Various Years). Finance accounts. Finance Department.

Government of Odisha. (2023). *Medium-term fiscal plan (MTFP) 2023-24 to 2025-26*. Finance Department.

Government of Odisha. (2023). *Odisha economic survey 2022-23*. Planning & Convergence Department.

Ghosh, S. (2021). Performance-linked grants for health in the 15th Finance Commission: A critical appraisal. Economic & Political Weekly, 56(15), 41–48.

Gulati, A., & Saini, S. (2021). The political economy of food subsidies in India. Routledge.

Gupta, A. S. (2007). Determinants of tax revenue efforts in developing countries (IMF Working Paper No. WP/07/184). International Monetary Fund. https://doi.org/10.5089/9781451867480.001

Howes, S., Jha, S., & Shankar, S. (2017). Stabilising state finances: The Odisha experience. In M. G. Rao (Ed.), Studies in Indian public finance (pp. 234–259). Oxford University Press.

Inman, R. P., & Rubinfeld, D. L. (1997). Rethinking federalism. Journal of Economic Perspectives, 11(4), 43–64. https://doi.org/10.1257/jep.11.4.43

Jha, R. (2018). The political economy of fiscal reforms in Odisha. Centre for Development Studies.

Jha, R., Panda, M., & Sharma, A. (2021). Measuring tax efficiency and effort in Indian states using stochastic frontier analysis. Indian Journal of Public Economics, 65(3), 301–322.

Keen, M., & Lockwood, B. (2010). The value added tax: Its causes and consequences. Journal of Development Economics, 92(2), 138–151. https://doi.org/10.1016/j.jdeveco.2009.01.012

Khemani, S. (2007). Does delegation of fiscal policy to an independent agency make a difference? Evidence from intergovernmental transfers in India. Journal of Development Economics, 82(2), 464–484. https://doi.org/10.1016/j.jdeveco.2006.04.001

Lotz, J. R., & Morss, E. R. (1967). Measuring "tax effort" in developing countries. IMF Staff Papers, 14(3), 478–499. https://doi.org/10.2307/3866256

Lütkepohl, H. (2005). New introduction to multiple time series analysis. Springer-Verlag. https://doi.org/10.1007/978-3-540-27752-1

Mishra, B. (2015). Fiscal correction and development in Odisha: A political economy perspective. Odisha Economic Association Journal, 12(1), 23–45.

Musgrave, R. A. (1959). The theory of public finance: A study in public economy. McGraw-Hill.

Oates, W. E. (1972). Fiscal federalism. Harcourt Brace Jovanovich.

Oates, W. E. (1999). An essay on fiscal federalism. Journal of Economic Literature, 37(3), 1120–1149. https://doi.org/10.1257/jel.37.3.1120

Panagariya, A., & Rao, M. G. (2017). The making of miracles in Indian states. Oxford University Press.

Prabhu, S. E. (2012). Fiscal decentralization and local government finances. Concept Publishing.

Prud'homme, R. (1995). The dangers of decentralization. The World Bank Research Observer, 10(2), 201–220. https://doi.org/10.1093/wbro/10.2.201

Rao, M. G. (2000). Taxable capacity and tax effort of Indian states: An empirical study. National Institute of Public Finance and Policy.

Rao, M. G. (2011). Goods and Services Tax in India: Progress and prospects. Economic & Political Weekly, 46(23), 16–19.

Rao, M. G., & Singh, N. (2005). The political economy of federalism in India. Oxford University Press.

Rangarajan, C., & Srivastava, D. K. (2008). Reforming India's fiscal transfer system: Resolving vertical and horizontal imbalances. Economic & Political Weekly, 43(23), 47–60.

Reddy, Y. V. (2019). Resource rents and fiscal federalism: The case of Indian states. Academic Foundation.

Reserve Bank of India. (2022). Handbook of statistics on Indian states.

Reserve Bank of India. (2023). *State finances: A study of budgets for 2022-23*.

Rodden, J. (2002). The dilemma of fiscal federalism: Grants and fiscal performance around the world. American Journal of Political Science, 46(3), 670–687. https://doi.org/10.2307/3088406

Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. The Stata Journal, 9(1), 86–136. https://doi.org/10.1177/1536867X0900900106

Sacchi, A., & Salotti, S. (2014). The impact of national fiscal rules on the stabilisation function of fiscal policy. European Journal of Political Economy, 35, 47–61. https://doi.org/10.1016/j.ejpoleco.2014.03.006

Shah, A. (2004). Fiscal decentralization in developing and transition economies: Progress, problems, and the promise (World Bank Policy Research Working Paper No. 3282). The World Bank. https://doi.org/10.1596/1813-9450-3282

Sims, C. A. (1980). Macroeconomics and reality. Econometrica, 48(1), 1–48. https://doi.org/10.2307/1912017

Singh, N., & Srinivasan, T. N. (2006). Federalism and economic development in India: An assessment (Working Paper). Stanford Center for International Development.

Smart, M. (1998). Taxation and deadweight loss in a system of intergovernmental transfers. Canadian Journal of Economics, 31(1), 189–206. https://doi.org/10.2307/136378

Sridhar, V. (2022). Financing disaster resilience: Lessons from the 15th Finance Commission. Indian Journal of Public Administration, 68(2), 234–250. https://doi.org/10.1177/00195561221083651

Srivastava, D. K., & Sen, T. K. (1997). Government subsidies in India. National Institute of Public Finance and Policy.

Stiglitz, J. E. (2015). The origins of inequality, and policies to contain it. National Tax Journal, 68(2), 425–448. https://doi.org/10.17310/ntj.2015.2.09

Ter-Minassian, T. (1997). Fiscal federalism in theory and practice. International Monetary Fund.

Tiebout, C. M. (1956). A pure theory of local expenditures. Journal of Political Economy, 64(5), 416–424. https://doi.org/10.1086/257839

Weingast, B. R. (2009). Second generation fiscal federalism: The implications of fiscal incentives. Journal of Urban Economics, 65(3), 279–293. https://doi.org/10.1016/j.jue.2008.12.005

World Bank. (2018). State fiscal reforms in India: Progress and prospects (South Asia Economic Focus). https://doi.org/10.1596/978-1-4648-1293-1

World Bank. (2021). Building resilience to natural disasters in Odisha: A case study (South Asia Disaster Risk Management Report). https://documents.worldbank.org/en/publication/documentsreports/documentdetail/099125006072213410/p1732520c9b7a00680b3a017d9cdf3d9db2

Zodrow, G. R., & Mieszkowski, P. (1986). Pigou, Tiebout, property taxation, and the underprovision of local public goods. Journal of Urban Economics, 19(3), 356–370. https://doi.org/10.1016/0094-1190(86)90048-3

To cite this article:Kangshun Geng, Xiaotao Zhang*. (2026). *How New Quality Productive Forces Interact with High-Quality Economic Development: Spatiotemporal Evidence from China, Journal of Financial and Economic Dynamics*, 1(1), 62-88;https://doi.org/10.66361/jfed.64

How New Quality Productive Forces Interact with High-Quality Economic Development: Spatiotemporal Evidence from China

KangShun Geng[1], XiaoTao Zhang[2]*

[1] KangShun Geng, School of Economics and Management, Suqian University, JiangSu , P.R.China

[2] XiaoTao Zhang, School of Civil Engineering and Architecture, Suqian University, JiangSu,P.R.China

**** Correspondence:** XiaoTao Zhang , zhangxt@squ.edu.cn*

Abstract: Promoting high-quality economic development has become one of the key factors of China's economic transformation. In this context, the concept of new quality productive forces has been proposed to characterize a development paradigm driven by innovation, digital transformation, industrial upgrading, and ecological sustainability. Understanding the interaction between new quality productive forces and high-quality economic development is therefore crucial for assessing structural transformation and regional development performance. This study investigates the coupling and coordination relationship between new quality productive forces and high-quality economic development in China from spatiotemporal and dynamic perspectives. Using panel data for 30 provincial-level regions from 2013 to 2022, comprehensive evaluation index systems are constructed for both systems. The entropy-weighted TOPSIS method is employed to measure their overall development levels, and a coupling coordination degree model is applied to evaluate their interactive relationship. Regional disparities are further decomposed using the Dagum Gini coefficient, while kernel density estimation and spatial Markov chain analysis are used to examine distributional dynamics, state transitions, and spatial spillover effects. The results show that the overall coupling coordination level in China has increased steadily over the study period, although it remains relatively low. Significant regional heterogeneity is observed, with eastern regions consistently exhibiting higher coordination levels than central and western regions. Subsystem analysis indicates that new quality labor is more closely aligned with high-quality economic development, whereas new quality means of production represents the main constraint, particularly in less developed regions. Further analysis reveals that interregional disparities are the primary source of spatial inequality in coupling coordination. Moreover, spatial Markov chain results identify strong path dependence and significant neighborhood effects, suggesting the existence of club convergence driven by spatial spillovers. Overall, the findings indicate that the coordinated evolution of new quality productive forces and high-quality economic development is jointly shaped by internal structural conditions and external spatial interactions, providing empirical insights for promoting more balanced and sustainable regional development in transitional economies.

Keywords: New quality productive forces; High-quality economic development; Coupling coordination degree; Spatial heterogeneity; Dynamic evolution

1. Introduction

Against the backdrop of profound transformations in the global economy, promoting high-quality economic development has become a central objective for many economies undergoing structural transition (Chen & Xing, 2025). In recent years, China has increasingly emphasized a shift away from extensive growth driven by

factor inputs toward a development model characterized by efficiency improvement, innovation, sustainability, and structural upgrading (Glawe, 2025). Within this context, the concept of new quality productive forces has been proposed as a development paradigm aimed at fostering innovation-driven productivity growth, industrial transformation, and green development (Zheng et al., 2025).

New quality productive forces represent an evolution of traditional productive forces, placing greater emphasis on qualitative improvement rather than simple quantitative expansion. They are commonly associated with breakthroughs in advanced technologies, more efficient allocation of production factors, digital transformation, and the cultivation of emerging and future industries (Shi et al., 2025). By enhancing total factor productivity and reshaping industrial structures, new quality productive forces are widely regarded as a key driving force of high-quality economic development (Dai & Zheng, 2025). At the same time, high-quality economic development requires productive forces that are compatible with new institutional arrangements, technological conditions, and sustainability objectives (Geels et al., 2023; Schmidt-Scheele and Mattes, 2025). This implies that new quality productive forces and high-quality economic development are not independent processes, but rather two interrelated systems that interact and co-evolve over time (Liu et al. ,2025c). Existing studies have explored new quality productive forces from both qualitative and quantitative perspectives. Qualitative research has primarily focused on conceptual definitions, theoretical foundations, and development pathways, highlighting the roles of technological innovation, green transformation, and digitalization in enhancing productivity (Yang et al., 2025; Liang & Huang, 2025). Quantitative studies, in contrast, have sought to measure the development level of new quality productive forces by constructing comprehensive indicator systems, although considerable variation remains in terms of dimensional frameworks and indicator selection. Common approaches include frameworks based on labour, means of production, and labour objects (Hu and Jia, 2025; Lei et al., 2025; Liu et al., 2025a), as well as alternative classifications that emphasize technological, digital, or ecological dimensions (Jiang, 2025; Lu, 2025).

An expanding body of literature has increasingly recognized the close relationship between productivity upgrading and high-quality economic development. Innovation driven improvements in productivity are widely regarded as a core determinant of high-quality growth (Nguyen et al., 2025), while appropriate institutional arrangements can reduce transaction costs and enhance the efficiency of resource allocation (Kafouros et al., 2024). From this perspective, new quality productive forces not only contribute to high-quality economic development but are also shaped by it. high-quality economic development provides the institutional and structural conditions under which the emission-reduction, efficiency enhancing, and sustainability effects of new quality productive forces can be effectively realized (Li & Wang, 2025).

Despite these advances, several research gaps remain. First, although existing studies have separately measured the development level of new quality productive forces or high-quality economic development, relatively limited attention has been paid to their interaction from a system coupling perspective. Second, most empirical analyses focus on static cross regional comparisons, while the dynamic evolution of the coupling relationship and the associated state transitions over time have received insufficient consideration. Third, although spatial disparities are frequently documented, the mechanisms through which neighboring regions influence the evolution of coupling coordination, particularly from dynamic and probabilistic perspectives have not been adequately explored.

This study examines the coupling coordination relationship between new quality productive forces and high-quality Economic development in China from spatiotemporal and dynamic perspectives. Using panel data for 30 provincial-level regions over the period 2013–2022, comprehensive evaluation index systems are first constructed for both new quality productive forces and high-quality economic development. The entropy weighted TOPSIS method is then employed to assess the overall development level of each system, followed by the application of a coupling coordination degree model to quantify their interactive relationship.

Subsequently, the Dagum Gini coefficient is used to decompose regional disparities and identify the sources of spatial inequality. Finally, kernel density estimation and spatial Markov chain analysis are adopted to investigate distributional dynamics, state transitions, and spatial spillover effects.

This study makes three main contributions. First, by conceptualizing new quality productive forces and high-quality economic development as two interdependent systems, this paper provides a systematic framework for evaluating their coupling coordination and evolutionary patterns. Second, the study offers a comprehensive empirical assessment of spatiotemporal disparities and dynamic transitions across regions, thereby enriching the literature with evidence from a large transitional economy. Third, by incorporating spatial Markov chain analysis, the study highlights the role of neighborhood effects in shaping the evolution of coupling coordination, offering insights into regional development patterns and policy coordination. Overall, the findings are expected to deepen the understanding of how productivity upgrading interacts with high-quality economic development and to provide empirical support for the formulation of regionally differentiated development strategies in transitional economies.

2. Theoretical analysis

The interaction between new quality productive forces and high-quality economic development can be conceptualized as a multidimensional coupling process, in which productivity upgrading and development quality mutually shape and reinforce each other (Xiao et al., 2025). To clarify this relationship, it is necessary to first examine the internal structure of each system and then elucidate the mechanisms through which they interact.

From the perspective of productivity theory, new quality productive forces represent a qualitative transformation of traditional productive forces. This transformation is not confined to technological progress alone, but also involves comprehensive changes in labor quality, production facilities, industrial structure, and ecological conditions (Lin et al., 2024). Accordingly, new quality productive forces can be decomposed into three interrelated dimensions: new quality labor, new quality means of production, and new quality labor objects.

New quality labor reflects the human capital foundation of production activities, encompassing labor skills, productivity, employment structure, and entrepreneurial capacity (Hosseinioun et al., 2025). Improvements in educational attainment, innovation-related employment, and labor productivity enhance the ability of the workforce to absorb new technologies and participate in advanced production processes (Shin et al., 2025). These changes provide essential support for innovation driven growth and structural upgrading, which constitute core components of high-quality economic development (He et al., 2025).

New quality means of production form the material and technological basis of production activities. This dimension covers traditional infrastructure, digital infrastructure, and investment in technological innovation (Wan et al., 2024). Upgraded transportation networks, enhanced digital connectivity, and sustained investment in research and development improve production efficiency, facilitate knowledge diffusion, and reduce transaction costs (Amankwah-Amoah et al., 2025). By strengthening the technological and infrastructural foundations of the economy, new quality means of production promote a transition toward more efficient, intelligent, and low-carbon production modes (Sharma et al., 2024).

New quality labor objects reflect changes in the content of production and in the ways production activities interact with the natural environment. The development of strategic emerging industries and future industries signals a shift in production patterns toward higher value-added and technology-intensive activities (Chen et al., 2024), while improvements in environmental quality and ecological regulation highlight the growing importance of sustainability constraints (Jin et al., 2025). Taking together, these changes indicate a reorientation of production activities toward long-term development objectives, rather than a narrow focus on short-term output expansion. High-quality economic development is a comprehensive concept that extends

beyond economic growth to encompass structural optimization, sustainability, openness, and inclusive welfare improvement (Hou, 2025). Consistent with this perspective, high-quality economic development can be understood through five key dimensions: Innovation, Coordination, Green development, Openness, and Sharing (Huang et al., 2022; Zhou et al., 2022). The Innovation dimension emphasizes the role of technological progress and innovative output in driving sustainable growth. The Coordination dimension focuses on the rationalization and upgrading of industrial structure, reflecting the alignment between sectoral development and overall economic efficiency. The Green development dimension highlights resource-use efficiency and environmental performance, addressing constraints arising from energy consumption and pollution. The Openness dimension captures the integration of the domestic economy into global markets through trade and investment, while the Sharing dimension reflects the inclusiveness of development outcomes in terms of consumption, public services, and income distribution.

The coupling mechanism between new quality productive forces and high-quality economic development operates through multiple channels. On the one hand, productivity upgrading promotes high-quality economic development by enhancing innovation capacity, optimizing industrial structure, alleviating environmental pressure, and expanding development opportunities (Okolo et al., 2025). Improvements in labor quality, production facilities, and industrial positioning directly contribute to innovation performance, structural coordination, and green transformation (Degirmenci et al., 2025). On the other hand, high-quality economic development reshapes the institutional and market environment for productivity upgrading. Innovation-oriented policies, environmental regulations, openness to global markets, and inclusive development objectives influence the direction, intensity, and effectiveness of the evolution of new quality productive forces (Benatti et al., 2024).

When the internal structures and development rhythms of the two systems are well aligned, a coordinated state emerges in which productivity upgrade and development quality mutually reinforce each other. By contrast, mismatches between productivity transformation and development objectives may lead to inefficiencies, structural imbalances, or increased environmental pressure, thereby weakening the level of coordination between the two systems (Lah, 2025). Importantly, this coupling process is dynamic and characterized by spatial heterogeneity (Feng et al., 2024). The evolution of both systems exhibits path dependence, shaped by accumulated technological capabilities, institutional adaptation, and adjustments in industrial structure over time (Wolf, 2025). Moreover, spatial interactions—such as factor mobility, industrial linkages, knowledge spillovers, and policy diffusion—connect the development trajectories of neighboring regions. These spatial linkages may generate positive spillover effects that facilitate upward transitions in coupling coordination, or conversely, reinforce low-level equilibrium traps in less developed regions (Tsangaris et al., 2024).

The coupling between new quality productive forces and high-quality economic development operates through identifiable transmission channels and feedback mechanisms. On the one hand, new quality productive forces promote high-quality development by enhancing innovation capacity, improving factor allocation efficiency, and accelerating industrial upgrading. High-level human capital, advanced production technologies, and digital infrastructure increase total factor productivity and facilitate the transition toward innovation-driven and green development patterns. On the other hand, high-quality economic development provides institutional, financial, and market support for the accumulation and upgrading of new quality productive forces. Regions with stronger economic quality typically possess better innovation ecosystems, higher fiscal capacity, and stronger absorptive capability, which in turn reinforce the growth of advanced production factors. Therefore, the relationship between the two systems is not unidirectional but forms a dynamic feedback loop, in which mutual reinforcement may generate cumulative advantages and spatial divergence over time. This interaction mechanism provides the theoretical foundation for the subsequent coupling coordination analysis.

Based on the above analysis, the coupling coordination between new quality productive forces and high-quality

economic development can be understood as the outcome of multidimensional interactions between the two systems, operating through channels such as innovation, structural adjustment, environmental constraints, and spatial spillovers. This theoretical framework provides the conceptual foundation for the construction of evaluation index systems and the subsequent empirical analysis of coupling coordination. The overall coupling mechanism between the two systems is illustrated in Figure 1.

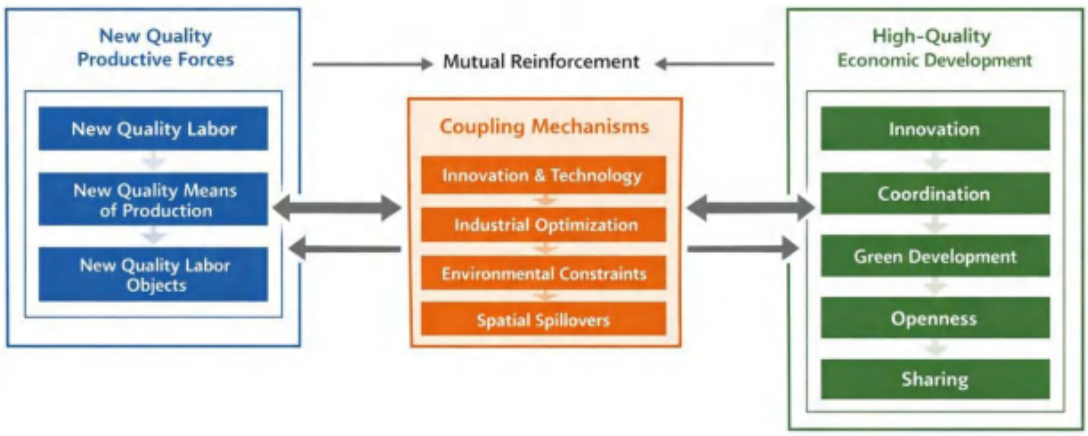


Figure 1 Coupling mechanism between new quality productive forces and high-quality economic development

3. Research Design

3.1 Construction of the Evaluation Index Systems

To examine the coupling coordination between new quality productive forces and high-quality economic development, this study constructs two comprehensive evaluation index systems. Adopting a systems-theoretic perspective, new quality productive forces and high-quality economic development are treated as two interrelated subsystems whose interactions and coordinated evolution can be quantitatively assessed.

3.1.1 Evaluation Index System for New Quality Productive Forces

In classical economic theory, productive forces consist of labor, means of production, and labor objects (Chu et al., 2025). Building on this framework, new quality productive forces emphasize innovation-driven development, modern industrial systems, digital transformation, and ecological sustainability (Zhang & Liu, 2025). Accordingly, this study constructs the evaluation index system for new quality productive forces along three dimensions: new quality labor, new quality means of production, and new quality labor objects.

The first dimension, new quality labor, is designed to capture the overall quality of the workforce, production efficiency, employment conditions, and entrepreneurial capacity. Indicators are selected from four aspects: labor skills, labor productivity, employment conditions, and entrepreneurial activity. Specifically, labor skills are measured by average years of education, human capital stock, and the share of education expenditure in fiscal spending. Labor productivity is represented by GDP per capita and the average wage of employed workers. Employment conditions are captured by the number of full-time equivalent R&D personnel per capita and the registered urban unemployment rate. Entrepreneurial activity is measured by the number of newly registered enterprises per 100 persons.

The second dimension, new quality means of production, reflects the material foundation and technological conditions that support production activities. This dimension covers traditional infrastructure, digital development, and technological innovation. Traditional infrastructure is measured by transportation network density, while digital development is captured by the number of broadband access ports, optical fiber density, and the scale of e-commerce sales. With respect to technological innovation, and in order to distinguish this subsystem from the measurement of innovation inputs and outputs within the high-quality economic

development system, this study primarily selects indicators that reflect the upgrading of production modes. These include the intensity of fiscal science and technology expenditure, R&D investment, technological transformation investment, the number of patent authorizations per capita, and the level of intellectual property protection.

The third dimension, new quality labor objects, reflects the transformation of production targets toward emerging industries and ecological sustainability. This dimension is characterized by the development of strategic emerging industries and future-oriented industries. Indicators such as the ratio of transaction value of strategic emerging industry projects to GDP and industrial robot installation density are used to capture the level of industrial upgrading. In addition, environmental indicators—including forest coverage rate, the intensity of environmental protection expenditure, and the strength of environmental regulation—are incorporated to comprehensively reflect the ecological attributes of production activities.

Taken together, these indicators constitute a multidimensional evaluation system that captures both the structural composition of productive forces and the qualitative upgrading of production. The detailed indicator system is reported in Table 1.

Table 1 Indicator system of new quality productive forces

Subsystems	Primary Indicators	Secondary Indicators	Attribute
New quality labor	Labor Force Skills	Average Years of Education Per Person	+
		Total Human Capital	+
		Ratio of Education Expenditure to Total Fiscal Expenditure	+
	Labor Productivity	GDP per capita	+
		Average Wage per Employee: Average wage of active employees	+
	Labor Force Employment	R&D Personnel Intensity: Full-time equivalent R&D personnel/total population	+
		Employment Willingness: Urban registered unemployment rate	–
	Labor Force Entrepreneurship	Number of newly registered enterprises per 100 people	+
New quality means of production	Traditional Infrastructure	Transportation network density: (Highway mileage + Railway mileage) / Administrative area	+
	Digital Development	Internet broadband access ports	+
		Optical Cable Line Length/Regional Area	+
		E-commerce sales	+
	Technological Innovation	Science and Technology Expenditures as a Percentage of Fiscal Expenditures	+
		Expenditures on new product development in high-tech industries	+
		Expenditure on technological transformation of high-tech industries	+
		Patents granted per capita	+
		Intellectual Property Protection Index	+
New quality labor objects	New Quality Industries	Transaction Value of Strategic Emerging Industries Projects / GDP	+
		Industrial Robot Installation Density	+

	Ecological Environment	Forest Coverage Rate	+
		Environmental Protection Intensity: Energy Conservation and Environmental Protection Expenditures / General Public Budget Expenditures	+
		Environmental regulation intensity: Industrial pollution control completed investment / Industrial added value	+

3.1.2 Evaluation Index System for High-Quality Economic Development

High-quality economic development in China is commonly conceptualized within the framework of the five development principles: Innovation, Coordination, Green development, Openness, and Sharing (Gao et al., 2024). Based on this framework, this study constructs an evaluation index system to capture the multidimensional nature of high-quality economic development. The detailed set of indicators is presented in Table 2.

Table 2 Indicator system of high-quality economic development

Subsystems	Primary Indicators	Secondary Indicators	Attribute
Innovation	Economic growth	GDP growth rate	+
	Innovation output	Ratio of technology market transaction value to GDP	+
Coordination	Rationalization of industrial Structure	Thiel index	−
	Upgrading of industrial Structure	Tertiary industry GDP / Secondary industry GDP	+
Green development	Energy consumption	Energy consumption per unit of GDP	−
	Environmental protection	Harmless treatment rate of domestic garbage	+
		Carbon emission emissions per unit of GDP	−
Openness	External capital dependence	Inward foreign direct investment (FDI) as a percentage of GDP	+
	Dependence on foreign trade	Total import and export as % of GDP	+
	Outward Foreign Direct Investment	Outward foreign direct investment (OFDI) as a percentage of GDP	+
Sharing	Consumption upgrade	Consumption per capita	+
	Healthcare sharing	Number of beds in medical institutions per capita	+
	Urban-rural development gap	Urban-rural income ratio: disposable income per capita of urban residents / disposable income per capita of rural residents	−

The Innovation dimension primarily reflects the endogenous driving forces of economic growth and the level of innovative output. Indicators are selected from two aspects—economic growth vitality and technological innovation outcomes, including the GDP growth rate and the ratio of technology market transaction value to GDP. Although innovation-related indicators also appear in the new quality productive forces system, their roles differ: in that system, innovation represents the configuration of advanced production factors, whereas here it captures the realized economic performance and output effects of innovation activities. This distinction helps maintain the conceptual independence of the two systems.

The Coordination dimension focuses on the degree of industrial structure optimization and is measured from two perspectives: industrial structure rationalization and industrial structure upgrading. Specifically, industrial

structure rationalization is characterized by using the Theil index, while industrial structure upgrading is captured by the ratio of value added in the tertiary sector to that in the secondary sector.

The Green development dimension emphasizes resource-use efficiency and environmental performance. Relevant indicators include energy consumption per unit of GDP, the harmless treatment rate of domestic waste, and carbon emission intensity, which jointly reflect resource constraints and environmental impacts in the process of economic development.

The Openness dimension reflects the degree of integration with the global economy and is measured using indicators such as dependence on foreign direct investment, trade openness, and the intensity of outward foreign direct investment.

The Sharing dimension highlights the inclusiveness of development outcomes and incorporates indicators related to consumption levels, availability of medical resources, and the urban–rural income gap.

Overall, this evaluation index system is designed to capture not only economic growth performance but also structural quality, sustainability, openness, and social inclusiveness.

3.2 Data Sources and Sample Description

This study employs panel data for 30 provincial-level regions in China over the period 2013–2022. Due to data availability constraints, Tibet as well as Hong Kong, Macao, and Taiwan are excluded from the analysis. Following the conventional regional classification widely used in the literature, the sample provinces are grouped into eastern, central, and western regions to facilitate spatial comparison (Xu et al., 2025; Liu et al., 2025b).

The data are collected from multiple authoritative sources, including the China Statistical Yearbook, the China Science and Technology Statistical Yearbook, the China High-Technology Industry Statistical Yearbook, the China Energy Statistical Yearbook, the China Torch Statistical Yearbook, provincial statistical yearbooks, the China Intellectual Property Development Report, and data released by the International Federation of Robotics (IFR). All monetary variables are appropriately processed to ensure comparability across regions and over time.

3.3 Methodology

3.3.1 Entropy-Weighted TOPSIS Method

To comprehensively evaluate the development levels of the new quality productive forces system and the high-quality economic development system, this study employs the entropy-weighted TOPSIS method. By determining indicator weights based on information entropy, this approach effectively reduces the bias associated with subjective weighting schemes, while the TOPSIS framework enables the aggregation and ranking of multidimensional indicator systems (Geng et al., 2024).

Specifically, the original indicator data are first standardized to eliminate differences in units of measurement and magnitude across indicators. During this process, positive and negative indicators are treated differently to ensure directional consistency. For positive indicators, higher values correspond to better development performance, whereas for negative indicators, higher values indicate poorer performance; therefore, an inverse transformation is applied to negative indicators before normalization. Subsequently, indicator weights are calculated according to the principle of information entropy, and the standardized indicators are weighted accordingly. On this basis, the Euclidean distances between each region and both the positive ideal solution and the negative ideal solution are computed. The composite development level index of each system is then derived by comparing these distances.

Formally, the composite development level of region i can be defined as follows:

$$\begin{cases} D_i^+ = \sqrt{\sum_{j=1}^{m} (z_j^+ - z_{ij})^2}, z_j^+ = max\{z_{1j}, z_{2j}, \ldots, z_{nj}\} \\ D_i^- = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_j^-)^2}, z_j^- = min\{z_{1j}, z_{2j}, \ldots, z_{nj}\} \end{cases} \tag{1}$$

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{2}$$

In Equations (1)–(2), z_{ij} represents the standardized and entropy-weighted value of indicator j for region i, while D_i^+ and D_i^- denote the Euclidean distances from region i to the positive ideal solution and the negative ideal solution, respectively. A larger value of S_i indicates a higher overall development level of the system.

3.3.2 Coupling Coordination Degree Model

To further examine the interactive relationship between new quality productive forces and high-quality economic development, this study employs a coupling coordination degree model (Norgaard, 1990). Drawing on coupling theory, this model is widely used to assess the degree of interaction and coordination between multiple subsystems and to reveal whether their development trajectories are aligned.

Let S_{nqpf} and $S_{\mathrm{h}qed}$ denote the composite development indices of new quality productive forces and high-quality economic development, respectively, as obtained from the entropy-weighted TOPSIS method. The coupling degree between the two systems is defined as:

$$C = \frac{2\sqrt{S_{nqpf} * S_{\mathrm{h}qed}}}{S_{nqpf} + S_{\mathrm{h}qed}} \tag{3}$$

The coupling degree reflects the intensity of interaction between the two systems, but it does not fully capture their coordinated development level. To address this limitation, a coordination index is further constructed by incorporating the overall development level of the two systems. Specifically, the comprehensive coordination index T is defined as a weighted sum of the two subsystem indices:

$$T = \alpha S_{nqpf} + \beta S_{\mathrm{h}qed} \tag{4}$$

where α and β represent the contribution weights of new quality productive forces and high-quality economic development, respectively. Following common practice in the literature, this study assigns equal weights to the two systems, setting $\alpha = \beta = 0.5$. Based on the coupling degree and the comprehensive coordination index, the coupling coordination degree D is calculated as:

$$D = \sqrt{C * T} \tag{5}$$

The coupling coordination degree integrates both the interaction intensity and the overall development level of the two systems, providing a more comprehensive measure of their coordinated evolution. A higher value of D indicates a stronger degree of coordination between new quality productive forces and high-quality economic development, whereas a lower value suggests a greater mismatch between the two systems.

3.3.3 Dagum Gini Coefficient Decomposition

To analyze the spatial disparities in the coupling coordination degree between new quality productive forces and high-quality economic development and to identify their sources, this study adopts the Dagum Gini coefficient decomposition method (Dagum, 1997). Compared with the traditional Gini coefficient, this approach allows the overall inequality to be decomposed into intra-regional disparity, inter-regional disparity, and hypervariable density, thereby effectively addressing the issue of distributional overlap across different regions. The decomposition of the overall Gini coefficient can be expressed as:

$$G=G_{\omega}+G_{nb}+G_{t} \tag{6}$$

In Equation (6), G_{ω} denotes intra-regional disparity, G_{nb} represents inter-regional disparity, and G_{t} refers to the contribution of hypervariable density. By comparing the relative contributions of these components, this study identifies the importance of different sources of disparity in shaping the overall spatial differentiation of coupling coordination.

3.3.4 Kernel Density Estimation

To further examine the distributional characteristics and dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, this study employs kernel density estimation. As a nonparametric estimation technique, kernel density estimation allows the probability density function of a variable to be inferred directly from sample data, without imposing a specific functional form. This method is particularly suitable for identifying changes in distributional shape, polarization, and convergence or divergence trends over time. Specifically, kernel density estimation is applied to the coupling coordination degree for different years to depict its temporal evolution. The estimated density function can be expressed as:

$$f(x)=\frac{1}{n\mathrm{h}}\sum_{i=1}^{n}K\left(\frac{x-X_i}{\mathrm{h}}\right) \tag{7}$$

where $f(x)$ denotes the estimated probability density function, $f(x)$ represents the coupling coordination degree, n is the sample size, h is the bandwidth parameter controlling the smoothness of the density curve, and $K(:)$ denotes the kernel function. Following common practice in the literature, a Gaussian kernel function is adopted in this study.

By comparing kernel density curves across different time periods, this study captures shifts in the distribution of coupling coordination, including changes in central tendency, dispersion, and the presence of multimodal structures. These features provide intuitive evidence on whether the coupling coordination degree exhibits convergence, divergence, or polarization during the study period, thereby complementing the results obtained from the coupling coordination model and the Dagum Gini coefficient decomposition.

3.3.5 Spatial Markov Chain Analysis

To further investigate the dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, as well as the influence of neighboring regions, this study employs spatial Markov chain analysis. Compared with the traditional Markov chain, the spatial Markov approach explicitly incorporates spatial dependence by conditioning transition probabilities on the development states of neighboring regions, thereby allowing neighborhood effects to be examined from a dynamic and probabilistic perspective.

Following common practice, the coupling coordination degree is first discretized into four ordered states—Basic, Intermediate, Advanced, and Superior—according to predefined classification criteria. Let y_{it} denote the state of region i at time t. The traditional Markov transition probability matrix describes the probability that a region shifts from state m at time t to state n at time t+1. The transition probability can be expressed as:

$$M=\begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix} \tag{8}$$

In Equation (8), P_{mn} represents the probability of transitioning from state m to state n, and the transition probability matrix satisfies the standard Markov property.

To account for spatial interactions, a spatial Markov transition framework is further constructed by conditioning state transitions on the spatial lag of the coupling coordination degree. Specifically, the spatial lag of region i at time t is defined based on a spatial weight matrix W, as follows:

$$W=\begin{bmatrix} P_{11|1} & P_{12|1} & P_{13|1} & P_{14|1} \\ P_{21|1} & P_{22|1} & P_{23|1} & P_{24|1} \\ P_{31|1} & P_{32|1} & P_{33|1} & P_{34|1} \\ \&P_{41|1} & \&P_{42|1} & \&P_{43|1} & \&P_{44|1} \\ \&P_{11|2} & \&P_{12|2} & \&P_{13|2} & \&P_{14|2} \\ \&\vdots & \&\vdots & \&\vdots & \&\vdots \\ \&P_{41|3} & \&P_{42|3} & \&P_{43|3} & \&P_{44|3} \\ \&P_{11|4} & \&P_{12|4} & \&P_{13|4} & \&P_{14|4} \\ \&P_{21|4} & \&P_{22|4} & \&P_{23|4} & \&P_{24|4} \\ \&P_{31|4} & \&P_{32|4} & \&P_{33|4} & \&P_{34|4} \\ \&P_{41|4} & \&P_{42|4} & \&P_{43|4} & \&P_{44|4} \end{bmatrix} \tag{9}$$

In equation (9), $P_{mn|k}$ denotes the probability that a province with initial state type m transitions to type n in the following year under neighborhood type k. When considering spatial spillover effects, this paper defines adjacency based on contiguity: regions in the spatial weight matrix are set to 1 if adjacent and 0 otherwise.

After prolonged state transitions, the coupling coordination degree between each province's new quality productive forces system and high-quality economic development system eventually reaches a stable state unaffected by temporal variations. Equations (10)-(11) compute this steady state, derived from the initial state and the Markov transition probability matrix.

$$\lim_{k\to\infty}\pi(k+1)=\lim_{k\to\infty}\pi(k)M \tag{10}$$

In Equation (10), π denotes the steady-state matrix of the Markov process, subject to the condition:

$$\sum_{i=1}^{n}\pi_i=1,\ 0\le\pi\le1 \tag{11}$$

By comparing the traditional Markov transition matrix and the spatial Markov transition matrices under different neighborhood contexts, this study examines whether and how neighborhood conditions affect the likelihood of upward or downward transitions in coupling coordination. A higher probability of upward transition when surrounded by high-level neighbors indicates positive spatial spillover effects, whereas a higher probability of persistence in lower states under low-level neighborhood conditions suggests spatial dependence that may reinforce low-level equilibrium traps.

Overall, spatial Markov chain analysis provides a dynamic framework for identifying path dependence, state persistence, and neighborhood effects in the evolution of coupling coordination. This method complements the results of kernel density estimation and Dagum Gini coefficient decomposition, offering deeper insights into the spatiotemporal dynamics of the coupling relationship between new quality productive forces and high-quality economic development.

4. Results

4.1 Temporal Evolution of Coupling Coordination at the National and Regional Levels

Based on the entropy-weighted TOPSIS method and the coupling coordination degree model, this study systematically calculated the coupling coordination degree between new quality productive forces and high-quality economic development for China as a whole and for each province over the period 2013–2022. The detailed results are reported in Table 3, which presents provincial values, regional averages, and national

trends.

At the national level, the average coupling coordination degree during the sample period was 0.443, indicating that the overall coordination level remained relatively low but exhibited a gradual improvement. According to commonly used classifications of coupling coordination stages, this level can be classified as a low coordination stage. Despite the relatively low initial level, the coupling coordination degree showed a clear upward trend, increasing from 0.435 in 2013 to 0.470 in 2022, with an average annual growth rate of approximately 0.87%. This pattern suggests that the interaction between new quality productive forces and high-quality economic development strengthened steadily over time.

In addition to the coupling coordination degree, this study further examines the relative development degree between the new quality productive forces system and the high-quality economic development system, which is defined as the ratio of their composite development levels. A value greater than one indicates that the development level of new quality productive forces exceeds that of high-quality economic development, whereas a value below one suggests the opposite. The results show that the national average relative development degree during the study period was 0.905. Moreover, the average relative development degree in the eastern, central, and western regions was consistently below one.

These findings indicate that, over the sample period, the development level of the high-quality economic development system generally exceeded that of the new quality productive forces system in China. This imbalance suggests that, in the short run, enhancing the overall development level of the new quality productive forces system would be conducive to improving the coupling coordination between the two systems.

At the provincial level, notable heterogeneity is observed. Provinces such as Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong exhibited relative development degree values greater than one, indicating that the development of new quality productive forces in these regions progressed more rapidly than high-quality economic development. In contrast, most other provinces recorded relative development degree values below one, reflecting a lag in the development of new quality productive forces relative to economic development quality.

Table 3 Degree of coupling coordination between new quality productive forces and high-quality economic development in China

Region	Province	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	Relative Development Level
Eastern China	Beijing	0.780	0.698	0.784	0.711	0.777	0.755	0.783	0.769	0.750	0.747	0.755	0.571
	Tianjin	0.612	0.517	0.580	0.562	0.551	0.550	0.585	0.560	0.579	0.583	0.568	0.646
	Hebei	0.344	0.324	0.358	0.334	0.373	0.432	0.406	0.410	0.411	0.408	0.380	0.982
	Liaoning	0.426	0.394	0.391	0.369	0.397	0.403	0.388	0.378	0.409	0.402	0.396	0.598
	Shanghai	0.634	0.599	0.697	0.643	0.671	0.700	0.695	0.682	0.707	0.743	0.677	0.716
	Jiangsu	0.590	0.512	0.583	0.545	0.578	0.573	0.566	0.580	0.618	0.604	0.575	1.662
	Zhejiang	0.541	0.492	0.568	0.524	0.563	0.577	0.572	0.593	0.610	0.632	0.567	1.101
	Fujian	0.454	0.572	0.458	0.478	0.495	0.488	0.468	0.471	0.496	0.501	0.488	1.340
	Shan dong	0.461	0.412	0.461	0.443	0.488	0.489	0.491	0.498	0.514	0.511	0.477	1.309
	Guang dong	0.646	0.571	0.654	0.609	0.659	0.675	0.682	0.708	0.702	0.699	0.660	1.771
	Hainan	0.424	0.377	0.415	0.392	0.493	0.456	0.453	0.435	0.483	0.507	0.443	0.340
	Mean	0.537	0.497	0.541	0.510	0.550	0.554	0.553	0.553	0.571	0.576	0.544	0.907
Central China	Shanxi	0.325	0.283	0.362	0.311	0.370	0.375	0.356	0.346	0.381	0.348	0.346	1.143
	Jilin	0.352	0.317	0.347	0.321	0.346	0.345	0.369	0.380	0.435	0.353	0.356	0.679
	Heilong	0.362	0.320	0.420	0.355	0.403	0.402	0.454	0.407	0.492	0.457	0.407	0.810

	jiang												
	Anhui	0.386	0.343	0.415	0.401	0.441	0.458	0.471	0.488	0.507	0.497	0.441	0.959
	Jiangxi	0.367	0.310	0.372	0.357	0.406	0.431	0.455	0.466	0.474	0.455	0.409	0.706
	Henan	0.366	0.339	0.378	0.367	0.404	0.414	0.419	0.420	0.431	0.457	0.400	0.896
	Hubei	0.406	0.372	0.437	0.406	0.466	0.488	0.478	0.444	0.513	0.480	0.449	0.991
	Hunan	0.381	0.344	0.387	0.391	0.428	0.413	0.427	0.454	0.490	0.494	0.421	0.692
	Mean	0.368	0.329	0.390	0.364	0.408	0.416	0.429	0.426	0.465	0.443	0.404	0.846
Western China	Guangxi	0.337	0.289	0.343	0.316	0.350	0.356	0.351	0.350	0.408	0.379	0.348	0.871
	Inner Mongolia	0.358	0.342	0.366	0.322	0.389	0.384	0.337	0.324	0.381	0.358	0.356	0.909
	Chong qing	0.405	0.366	0.420	0.381	0.426	0.416	0.411	0.415	0.443	0.441	0.412	0.817
	Sichuan	0.435	0.397	0.399	0.364	0.426	0.431	0.415	0.442	0.472	0.452	0.423	1.171
	Guizhou	0.358	0.292	0.325	0.304	0.354	0.351	0.344	0.345	0.373	0.407	0.345	0.974
	Yunnan	0.361	0.296	0.343	0.306	0.347	0.348	0.342	0.341	0.352	0.359	0.339	0.812
	Shaanxi	0.538	0.486	0.464	0.545	0.443	0.504	0.451	0.434	0.449	0.450	0.477	1.137
	Gansu	0.330	0.285	0.318	0.326	0.341	0.337	0.314	0.306	0.337	0.387	0.328	0.626
	Qinghai	0.375	0.345	0.407	0.372	0.390	0.377	0.356	0.310	0.330	0.316	0.358	1.227
	Ningxia	0.349	0.370	0.428	0.356	0.362	0.376	0.368	0.335	0.361	0.339	0.364	1.162
	Xinjiang	0.333	0.303	0.327	0.302	0.333	0.336	0.340	0.305	0.346	0.324	0.325	0.702
	Mean	0.380	0.343	0.376	0.354	0.378	0.383	0.366	0.355	0.386	0.383	0.371	0.954
Nationwide Mean		0.435	0.396	0.440	0.414	0.449	0.455	0.451	0.447	0.475	0.470	0.443	0.905

In terms of growth dynamics, the central region recorded the highest average annual increase in the coupling coordination degree, indicating a tendency toward partial convergence with the eastern region. By contrast, the western region experienced only modest improvement, suggesting that the gap between western provinces and more developed regions continued to widen during the sample period.

At the provincial level, Beijing, Shanghai, Guangdong, Zhejiang, and Jiangsu consistently ranked among the top provinces in terms of coupling coordination. These provinces are characterized by relatively advanced innovation systems, higher levels of industrial upgrading, and stronger institutional support for high-quality economic development. In contrast, several western provinces remained at comparatively low coordination levels for most of the study period, reflecting persistent structural constraints and limited accumulation of new quality productive forces.

4.2 Coupling Coordination between Subsystems of New Quality Productive Forces and High-Quality Economic Development

To further explore the internal structure of coupling coordination, this study examines the interactions between the subsystems of new quality productive forces—new quality labor, new quality means of production, and new quality labor objects—and high-quality economic development. The results are summarized in Table 4, which reports the coupling coordination degree between each subsystem and high-quality economic development at the national level as well as across eastern, central, and western regions.

Table 4 Degree of coupling coordination between new quality productive forces subsystem and high-quality economic development in China

Year	Labor - Economy				Means of Production - Economy				Labor Objects - Economy			
	Overall	East	Central	West	Overall	East	Central	West	Overall	East	Central	West
2013	0.481	0.593	0.396	0.406	0.439	0.567	0.361	0.321	0.448	0.519	0.364	0.421
2014	0.484	0.601	0.397	0.405	0.440	0.570	0.361	0.324	0.374	0.452	0.282	0.341

2015	0.472	0.586	0.384	0.396	0.436	0.561	0.364	0.323	0.480	0.546	0.435	0.428
2016	0.483	0.595	0.406	0.401	0.437	0.566	0.374	0.310	0.395	0.437	0.338	0.371
2017	0.495	0.600	0.424	0.421	0.450	0.573	0.391	0.330	0.460	0.536	0.429	0.393
2018	0.500	0.604	0.435	0.422	0.450	0.571	0.392	0.329	0.480	0.560	0.445	0.410
2019	0.506	0.615	0.445	0.419	0.452	0.574	0.397	0.330	0.474	0.559	0.462	0.378
2020	0.508	0.623	0.454	0.406	0.453	0.578	0.408	0.320	0.460	0.537	0.442	0.380
2021	0.526	0.635	0.484	0.425	0.466	0.587	0.425	0.334	0.505	0.564	0.507	0.430
2022	0.522	0.637	0.470	0.419	0.468	0.592	0.422	0.337	0.493	0.580	0.458	0.414
Mean	0.498	0.609	0.429	0.412	0.449	0.574	0.390	0.326	0.457	0.529	0.416	0.397

At the national level, the coupling coordination degree between new quality labor and high-quality economic development remained relatively stable during the study period, with values generally fluctuating between 0.47 and 0.50. This subsystem consistently exhibited the highest coordination level among the three subsystems, indicating a comparatively stronger alignment between labor-related improvements and the overall quality of economic development.

The coupling coordination degree between new quality means of production and high-quality economic development was slightly lower, with national average values mostly ranging from 0.43 to 0.45. Although this subsystem showed a gradual upward trend over time, its coordination level remained below that of new quality labor, suggesting a relatively slower alignment between production conditions and high-quality development outcomes.

By contrast, the coupling coordination degree between new quality labor objects and high-quality economic development displayed greater volatility and a generally lower level. National-level values varied more substantially over the sample period, reflecting uneven progress in the transformation of production targets toward emerging industries and environmentally sustainable activities.

Marked regional disparities are also evident across all three subsystems. As shown in Table 4, the eastern region consistently recorded the highest coupling coordination degrees for each subsystem, followed by the central region, while the western region lagged behind. This regional ranking remained stable throughout the study period, indicating persistent spatial heterogeneity in subsystem-level coordination patterns.

In terms of relative performance across subsystems, new quality labor exhibited the highest coordination level with high-quality economic development in all three regions, whereas new quality labor objects generally showed the weakest coordination, particularly in the central and western regions. These results suggest that, during the sample period, improvements in labor quality were more closely aligned with high-quality economic development than transformations in production means and labor objects.

4.3 Spatial Inequality and Sources of Regional Disparities

To examine spatial inequality in the coupling coordination degree between new quality productive forces and high-quality economic development, this study employed the Dagum Gini coefficient and its decomposition. The overall disparity G, intra-regional disparity G_{ω}, inter-regional disparity G_{nb}, and their corresponding contribution rates G_z were calculated, with the results reported in Table 5. In addition, Figure 2(a)–Figure 2(c) provide a visual illustration of the temporal evolution and structural composition of spatial inequality.

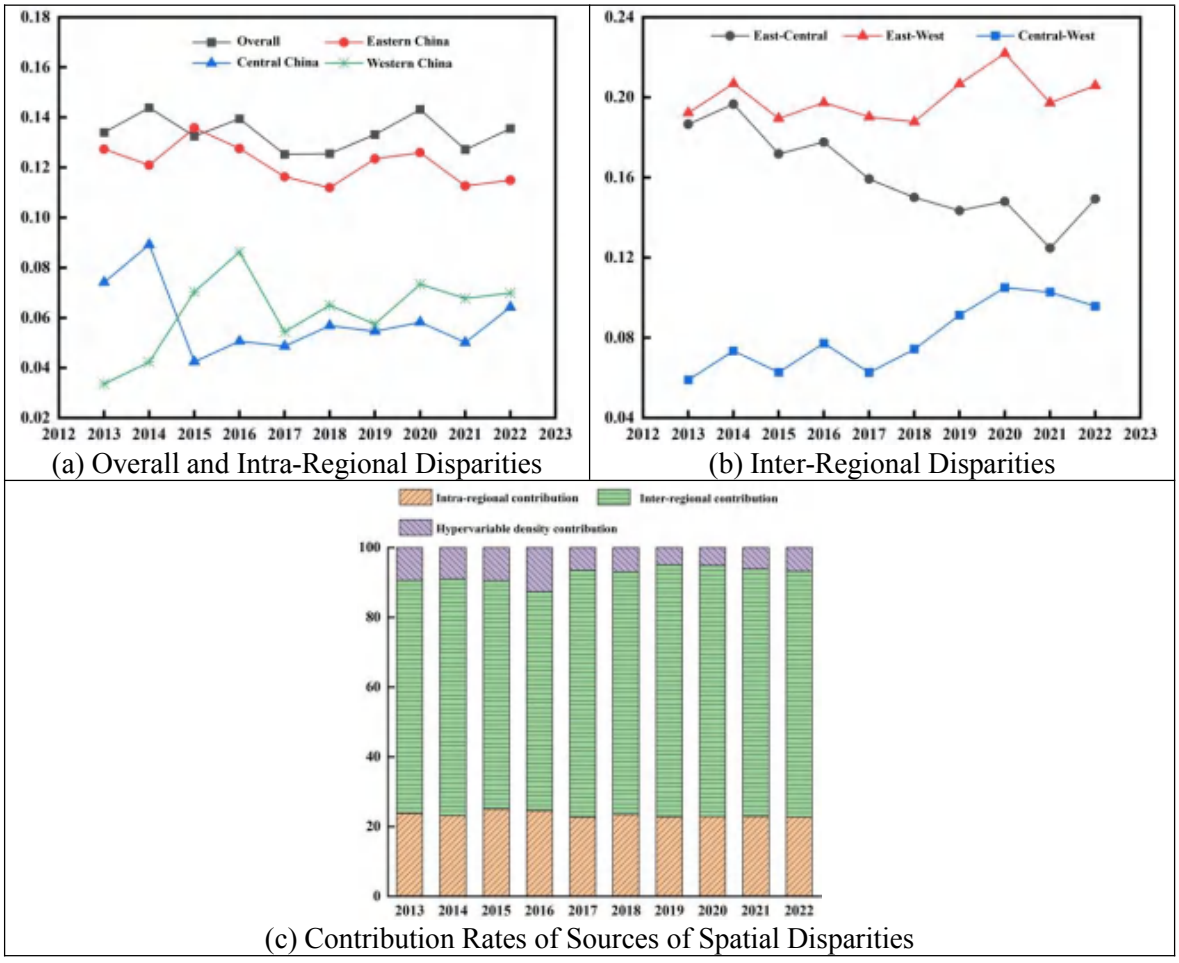
At the national level, the overall Gini coefficient exhibited a slight but persistent upward trend from 2013 to 2022, indicating a gradual widening of spatial disparities in coupling coordination. As shown in Table 5, the mean value of the overall Gini coefficient during the sample period was 0.161, suggesting a moderate level of inequality that did not substantially decline over time. This trend is visually reflected in Figure 2(a), which shows an increasing dispersion in the distribution of coupling coordination across provinces.

Decomposition results indicate that inter-regional disparity was the dominant source of overall spatial

inequality throughout the study period. On average, inter-regional disparity accounted for approximately 68.87% of total inequality, highlighting pronounced differences among the eastern, central, and western regions. As illustrated in Figure 2(b), the contribution of inter-regional disparity consistently exceeded that of intra-regional disparity and hypervariable density, underscoring the persistent role of regional gaps in shaping spatial inequality.

Table 5 Dagum Gini coefficients and contribution rates

Year	G	G_ω			G_{nb}			G_z（%）		
		East	Central	West	East-Central	East-West	Central-West	intra-regional	inter-regional	hypervariable density
2013	0.134	0.127	0.074	0.034	0.187	0.192	0.059	23.81	66.77	9.42
2014	0.144	0.121	0.089	0.042	0.197	0.207	0.073	23.17	67.83	9.00
2015	0.132	0.136	0.042	0.070	0.172	0.189	0.063	25.05	65.42	9.53
2016	0.139	0.128	0.051	0.086	0.178	0.197	0.077	24.55	62.79	12.66
2017	0.125	0.116	0.049	0.054	0.159	0.190	0.063	22.71	70.77	6.52
2018	0.126	0.112	0.057	0.065	0.150	0.188	0.074	23.43	69.63	6.94
2019	0.133	0.123	0.055	0.058	0.143	0.207	0.091	22.76	72.34	4.90
2020	0.143	0.126	0.058	0.073	0.148	0.222	0.105	22.89	71.89	5.22
2021	0.127	0.113	0.050	0.068	0.125	0.197	0.103	22.88	70.87	6.25
2022	0.136	0.115	0.064	0.070	0.149	0.206	0.096	22.81	70.41	6.78
Mean	0.134	0.122	0.059	0.062	0.161	0.200	0.080	23.41	68.87	7.72



(a) Overall and Intra-Regional Disparities

(b) Inter-Regional Disparities

(c) Contribution Rates of Sources of Spatial Disparities

Figure 2 Temporal evolution and decomposition of the Gini coefficient

By contrast, intra-regional disparity contributed a smaller but non-negligible share to overall inequality. As reported in Table 5, the average contribution of intra-regional disparity was 23.41%, indicating the presence of heterogeneity among provinces within the same region. This pattern is also evident in Figure 2(b), where intra-regional disparity remained secondary relative to inter-regional disparity throughout the study period.

The contribution of hypervariable density, which captures distributional overlap across regions, was relatively limited. The average contribution of hypervariable density was 7.72%, suggesting that overlapping distributions played a minor role in shaping overall spatial inequality. This finding is further confirmed by Figure 2(c), which shows that the hypervariable density component remained consistently low compared with the other two sources of disparity.

Further disaggregation reveals that disparities between the eastern and western regions contributed most to inter-regional inequality, followed by differences between the eastern and central regions, while disparities between the central and western regions were comparatively smaller. Taken together, the combined evidence from Table 5 and Figure 2(a)–(c) indicates that spatial inequality in the coupling coordination degree was largely driven by persistent inter-regional disparities, with limited convergence observed during the study period.

4.4 Dynamic Evolution and Spatial Transition of Coupling Coordination

4.4.1 Kernel Density Estimation

To explore the distributional dynamics of the coupling coordination degree between new quality productive forces and high-quality economic development, kernel density estimation was applied at the national level and for the eastern, central, and western regions. The results are illustrated in Figure 3(a)–Figure 3(d).

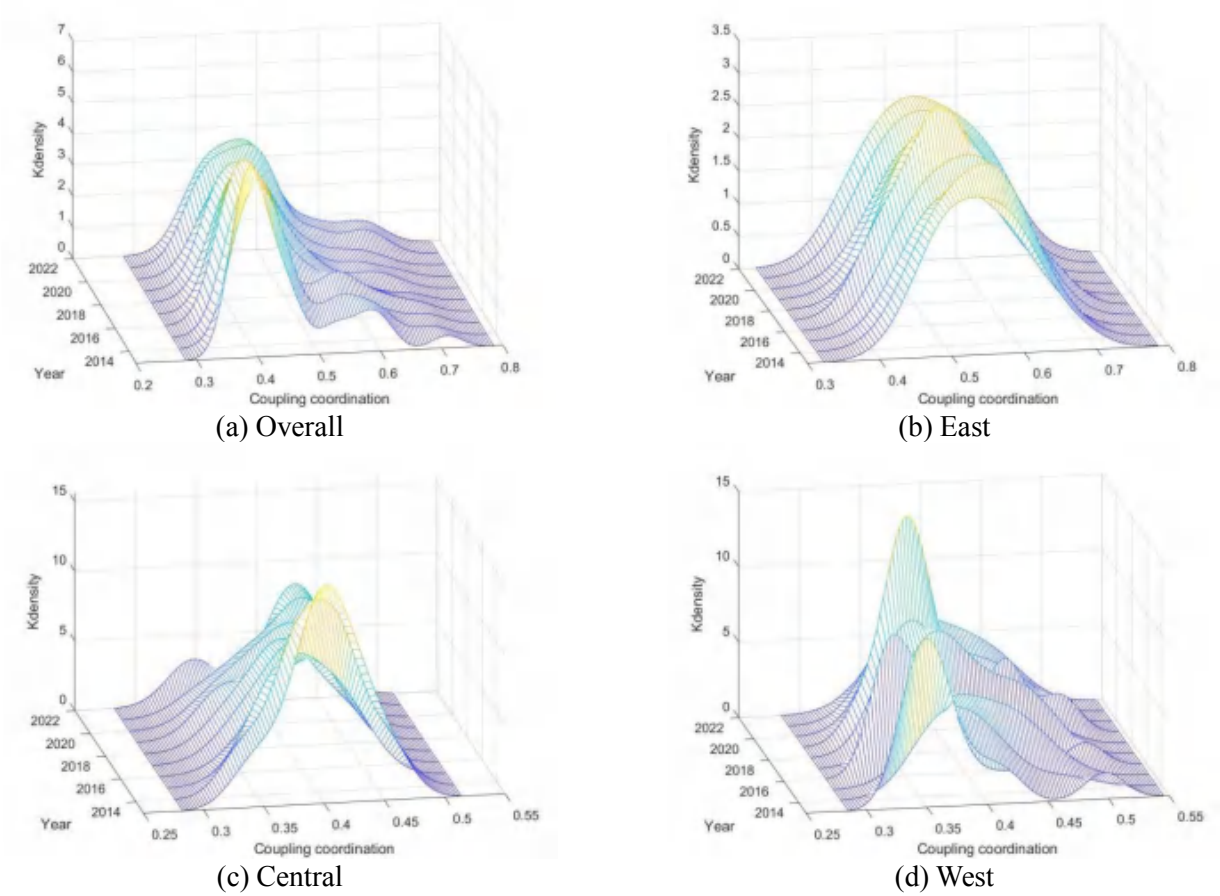
Figure 3(a) depicts the evolution of the national distribution of the coupling coordination degree. The density curves are characterized by a left-shifted peak, indicating that provinces with relatively low coordination levels accounted for a large proportion of the sample. Over time, the main peak gradually shifted to the right, suggesting an overall improvement in the coupling coordination degree, although the magnitude of this increase remained limited. Meanwhile, the height of the main peak declined and the distribution became wider, accompanied by a noticeable tailing effect. The emergence of secondary peaks further indicates the presence of polarization, reflecting increasing heterogeneity among provinces at the national level. This polarization may be associated with uneven policy support, differential factor mobility, and the agglomeration of innovation resources in leading regions, which reinforce cumulative advantages. Meanwhile, regions with weaker industrial foundations or limited access to advanced production factors may experience slower improvement, thereby widening the distributional gap.

Figure 3(b) presents the distributional dynamics for the eastern region. In contrast to the national pattern, the peak of the density curve was located closer to the middle range and exhibited no pronounced tailing effect. The main peak shifted steadily to the right, indicating that a relatively large number of provinces achieved higher levels of coupling coordination than the national average. Moreover, the height of the main peak increased over time, implying a gradual reduction in intra-regional disparities within the eastern region.

Figure 3(c) illustrates the distributional dynamics for the central region. The peak of the density curve was concentrated toward the lower range, indicating that provinces with relatively low levels of coupling coordination accounted for a large share of the region. Over time, the main peak exhibited a moderate rightward movement, suggesting an overall improvement in the coupling coordination degree. Temporary secondary peaks emerged in certain years, reflecting short-lived polarization rather than a persistent structural divide. Meanwhile, the widening of the density curve indicates an expansion of intra-regional disparities in the central region.

Figure 3(d) illustrates the kernel density estimates for the western region. Similar to the central region, the

main peak was positioned on the left side of the distribution, reflecting generally low coordination levels. The gradual rightward shift of the peak indicates an overall increase in the coupling coordination degree. However, the persistent presence of secondary peaks, together with an expanding distribution width and tailing effects, reveals a growing degree of internal heterogeneity and polarization within the western region.



(a) Overall (b) East

(c) Central (d) West

Figure 3 Kernel density estimation

Overall, the kernel density estimates for China as a whole and for the three major regions consistently exhibit a rightward shift of the main peak, indicating a continuous increase in the coupling coordination degree over the study period. The dynamic evolution of peak positions corresponds closely to the observed changes in coupling coordination levels. At the same time, intra-regional disparities narrowed in the eastern region but expanded in the central and western regions, contributing to a widening trend in interprovincial disparities at the national level.

4.4.2 Markov Chain and Spatial Markov Analysis

To further investigate the dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, both traditional Markov chain analysis and spatial Markov chain analysis were employed. Based on the estimated transition probabilities, the evolutionary tendency of coupling coordination was further examined.

(1) Traditional Markov Chain Analysis

A traditional Markov transition probability matrix was first constructed to analyze the intrinsic evolution of the coupling coordination degree without explicitly accounting for spatial interactions. The corresponding transition probability matrix is reported in Table 6, where the coupling coordination degree was classified into four ordered states: Basic, Intermediate, Advanced, and Superior.

Table 6 Traditional Markov transition probability matrix

t\t+1	n	Basic	Intermediate	Advanced	Superior
Basic	70	0.686	0.286	0.029	0
Intermediate	68	0.265	0.471	0.250	0.015
Advanced	68	0.029	0.176	0.632	0.162
Superior	64	0	0	0.125	0.875

As shown in Table 6, the diagonal elements of the transition matrix are consistently higher than the off-diagonal elements, indicating strong state persistence. In particular, the Superior state exhibits the highest persistence probability, with 87.5% of provinces remaining in the same state in the subsequent period. This is followed by the Basic state, which shows a persistence probability of 68.6%, suggesting pronounced stability at both low and high coordination levels.

Downward transition probabilities decrease as the coordination level rises. Specifically, provinces in the Intermediate state have a 26.5% probability of transitioning downward in the next period, while this probability declines to 20.5% for the Advanced state and further to 12.5% for the Superior state. These results indicate that provinces with higher coupling coordination levels face a relatively lower risk of deterioration. Overall, the traditional Markov results suggest that the evolution of coupling coordination follows a gradual upward trajectory, characterized by strong path dependence and a stepwise transition pattern.

(2) Spatial Markov Chain Analysis

The state of neighboring regions may influence the transition path of a province's coupling coordination state in the subsequent period. To capture this effect, a binary (0–1) spatial weight matrix was adopted as the spatial weight matrix in the Markov chain framework, and the corresponding spatial transition probabilities were calculated.

The spatial Markov transition probability matrix is reported in Table 7. Compared with the traditional Markov transition matrix shown in Table 6, substantial changes in transition probabilities are observed, indicating that spatial factors play an important role in shaping state transitions. The statistical significance of spatial spillover effects can be tested using Equation (12). The null hypothesis is that state transitions across regions are mutually independent and unrelated to the states of neighboring regions:

$$Q_b=-2\,log\left\{\prod_{l=1}^{k}\prod_{i=1}^{k}\prod_{j=1}^{k}\left[\frac{p_{ij}}{p_{ij}(S)}\right]^{n_{ij}(S)}\right\} \tag{12}$$

In Equation (12), k denotes the number of states, which is set to 4 in this study; p_{ij} represents the transition probability in the traditional Markov chain; $p_{ij}(S)$ denotes the spatial Markov transition probability conditional on the neighboring state S; and $n_{ij}(S)$ refers to the number of observed transitions under neighboring state S. The test statistic Q_b follows a chi-square distribution with degrees of freedom $k(k\text{-}1)^2$. In this study, the value of Q_b is 87.992, with a corresponding p-value of 0.000. At the significance level of α=0.005, the null hypothesis of independent state transitions is rejected, providing strong evidence of spatial spillover effects.

As shown in Table 7, the coupling coordination states exhibit a clear pattern of spatial clustering. For example, when the neighboring state is Basic, the number of observations that remain in the Basic state in both the current and subsequent periods (n = 19) is substantially higher than the corresponding numbers for other states (n = 7, 3, and 1). Similarly, when the neighboring state is Superior, the number of observations remaining in the Superior state (n = 37) is markedly higher than those transitioning to other states (n = 13, 1, and 0). The spatial Markov transition results remain stable under alternative specifications of the spatial weight matrix.

Using an economic distance matrix yields consistent transition probabilities, confirming robustness.

Table 7 Spatial Markov transition probability matrix

Neighborhood Type	t\t+1	n	Basic	Intermediate	Advanced	Superior
Basic	Basic	19	0.737	0.211	0.053	0
	Intermediate	7	0.143	0.714	0.143	0
	Advanced	3	0	0.667	0.333	0
	Superior	1	0	0	1.000	0
Intermediate	Basic	40	0.700	0.275	0.025	0
	Intermediate	39	0.308	0.462	0.231	0
	Advanced	16	0.063	0.250	0.563	0.125
	Superior	6	0	0	0.333	0.667
Advanced	Basic	11	0.545	0.455	0	0
	Intermediate	19	0.263	0.474	0.263	0
	Advanced	30	0.033	0.133	0.700	0.133
	Superior	19	0	0	0.158	0.842
Superior	Basic	0	0	0	0	0
	Intermediate	1	0	0	1.000	0
	Advanced	13	0	0	0.692	0.308
	Superior	37	0	0	0.027	0.973

Moreover, when a province is initially in the Basic state, the probability of upward transition increases with the coordination level of neighboring regions. Specifically, when the neighboring states are Basic, Intermediate, and Advanced, the probabilities of upward transition are 26.9%, 30.0%, and 45.5%, respectively. Notably, when the neighboring state is Superior, no observations remain in the Basic state in the subsequent period.

These results indicate that the spatial Markov transition probability matrix exhibits a pronounced club convergence pattern in the spatial dimension. Under the influence of neighboring states, regions are more likely to experience upward transitions rather than downward transitions, and the probability of upward mobility increases as the coordination level of neighboring regions rises. Overall, the spatial Markov analysis suggests that the coupling coordination degree between new quality productive forces and high-quality economic development in China follows a gradual upward evolution path shaped by significant spatial spillover effects.

(3) Evolution Trend Prediction of Coupling Coordination Degree

The long-term evolution trend of the coupling coordination degree can be effectively predicted by deriving the steady-state distribution of the Markov transition probability matrix. Table 8 reports the predicted long-run distribution of coupling coordination states for China.

Table 8 Predicted evolutionary trend of coupled coordination degree state types in China

Type		Basic	Intermediate	Advanced	Superior
No spatial spillover effects	Initial state	0.233	0.367	0.167	0.233
	Steady state	0.182	0.187	0.265	0.366

Spatial spillover effects	Steady state	Basic	0.302	0.556	0.143	0.000
		Intermediate	0.358	0.299	0.249	0.093
		Advanced	0.151	0.217	0.343	0.289
		Superior	0	0	0.081	0.919

When spatial spillover effects are not considered, the steady-state distribution obtained from the traditional Markov transition matrix shows a clear upward shift in coordination levels. Compared with the initial distribution, the numbers of provinces in the Basic, Intermediate, and Advanced states all decline, while the number of provinces in the Superior state increases markedly. This result indicates that, in the long run, the coupling coordination degree between new quality productive forces and high-quality economic development tends to evolve progressively from lower to higher states, reflecting a gradual improvement in overall coordination levels.

When spatial spillover effects are taken into account, the predicted evolution pattern of coordination states changes substantially. In the long run, provinces adjacent to regions in the Basic state are more likely to remain in relatively low coordination states, with 30.2% of observations remaining in the Basic state and 55.6% transitioning to the Intermediate state, while no provinces are expected to reach the Superior state under such neighborhood conditions. By contrast, when neighboring regions exhibit higher levels of coupling coordination, the probabilities of transitioning to the Advanced and Superior states are significantly higher than in other spatial contexts. These results suggest a pronounced Matthew effect in the coupling coordination between new quality productive forces and high-quality economic development across provinces.

Overall, based on current development trends, the long-term evolution of the coupling coordination degree in China appears relatively optimistic. The coordination between the two systems is expected to improve steadily over time, accompanied by a tendency toward high-level regional clustering. The number of provinces in higher coordination states increases progressively from lower to higher levels. Neighborhood spillover effects play a critical role in shaping this evolution: adjacency to low-level regions may constrain improvements in coordination or even induce downward transitions, whereas proximity to high-level regions facilitates upward mobility toward the Advanced and Superior states, reinforcing the overall upward trajectory of coupling coordination.

5. Discussion

From a spatiotemporal and dynamic evolutionary perspective, this study systematically examines the coupling coordination between new quality productive forces and high-quality economic development in China. The empirical findings not only characterize the overall pattern of coordinated evolution between the two systems, but also reveal substantial regional heterogeneity and structural differences in their interaction dynamics.

5.1 Staged Evolution of Overall Coupling Coordination

The results indicate that the coupling coordination degree between new quality productive forces and high-quality economic development exhibited a steady upward trend during the sample period, while the overall coordination level remained relatively low. This pattern suggests that the positive role of productivity upgrading in promoting high-quality economic development has gradually emerged, yet its comprehensive effects have not been fully realized. The cultivation of new quality productive forces involves multiple dimensions, including technological innovation, factor reallocation, and institutional adaptation. These processes are inherently gradual and often characterized by time lags, making it difficult to achieve a high level of coordination with high-quality economic development in the short run.

This finding is broadly consistent with existing studies. For example, Liu and He (2024) argue that although improvements in new quality productive forces can enhance development quality in the manufacturing sector, the early stages of transformation are frequently accompanied by structural frictions and adjustment costs, which lead to a gradual rather than immediate release of synergistic effects. In this sense, the "low-level initiation followed by steady improvement" pattern of coupling coordination identified in this study reflects the practical constraints faced by China's economic transition from scale-oriented growth toward a quality-driven development model.

5.2 Regional Heterogeneity and Differentiated Development Paths

From a spatial perspective, the coupling coordination degree between new quality productive forces and high-quality economic development exhibits pronounced regional heterogeneity. Overall, the eastern region remains in a leading position, the central region shows a clear catching-up trend, and the western region continues to lag behind. This spatial pattern largely mirrors the long-standing regional disparities observed in China's economic development trajectory.

The leading position of the eastern region can be attributed not only to its concentration of innovation resources and relatively complete industrial systems, but also to the cumulative interaction among these advantages. A denser innovation network, stronger market mechanisms, and deeper integration into global value chains enable a faster conversion of technological advances into productivity gains and industrial upgrading. This self-reinforcing process strengthens the feedback loop between new quality productive forces and high-quality economic development, thereby sustaining the region's leading status. By contrast, the central and western regions continue to face constraints related to industrial upgrading, technological foundations, and the efficiency of factor allocation, which weaken the transmission from productivity upgrading to improvements in development quality. This interpretation is consistent with the findings of Feng et al. (2024), who emphasize that disparities in technological bases and industrial structures across regions are key factors driving the differentiated development of new quality productive forces and their economic effects.

It is also noteworthy that the central region experienced a relatively faster improvement in coupling coordination, indicating a gradual catching-up process, whereas the western region exhibited more limited progress. This divergence suggests substantial differences across regions in their capacity to absorb industrial relocation, improve infrastructure, and optimize factor structures. More broadly, these patterns highlight the strong path-dependent nature of the coordinated evolution between new quality productive forces and

high-quality economic development, whereby historical endowments and accumulated advantages continue to shape regional development trajectories.

5.3 Explaining Structural Heterogeneity across Subsystems

From a subsystem perspective, pronounced differences are observed in the coupling coordination between the internal dimensions of new quality productive forces and high-quality economic development. Among the three subsystems, new quality labor exhibits a relatively higher level of coordination with high-quality economic development. This finding indicates that, at the current stage, improvements in human capital accumulation, labor productivity, and innovation-related employment are more readily translated into tangible development outcomes.

This result is consistent with the arguments of Degirmenci et al. (2025), who emphasize that human capital promotes sustainable development and high-quality growth by facilitating technological progress and green innovation. They further note that such effects tend to be more evident in regions with relatively mature institutional and market environments. In this context, the stronger coordination between new quality labor and high-quality economic development identified in this study reflects the comparatively direct and immediate role of labor-related factors in supporting innovation-driven and efficiency-oriented growth.

By contrast, the coupling coordination between the new quality means of production subsystem and high-quality economic development remains relatively weak. This pattern suggests that infrastructure modernization, digital transformation, and technological upgrading have not yet fully exerted their supporting role in some regions. One possible explanation is that such improvements typically require large-scale capital investment, long construction cycles, and complementary institutional adjustments, which delay their effective integration into the broader development system. As a result, the upgrading of production facilities may lag behind human capital improvements, thereby becoming a structural constraint on deeper coordination.

The new quality labor objects subsystem occupies an intermediate position in terms of coordination. This indicates that the development of strategic emerging industries and the strengthening of ecological constraints are gradually gaining importance, while their contribution to overall high-quality economic development is still in an accumulation phase. Taking together, these structural differences highlight the heterogeneous and asynchronous roles played by different elements of new quality productive forces in driving high-quality economic development, with each subsystem exerting its influence at a distinct pace.

5.4 Spatial Inequality, Path Dependence, and Neighborhood Effects

The decomposition results based on the Dagum Gini coefficient indicate that inter-regional disparity constitutes the primary source of spatial inequality in the coupling coordination degree between new quality productive forces and high-quality economic development. This finding suggests that long-standing differences across regions in terms of economic foundations, industrial structures, and institutional environments tend to be persistently amplified during the process of coupled and coordinated evolution. By contrast, the contributions of intra-regional disparity and hypervariable density are relatively limited, implying that adjustments within individual regions are unlikely to substantially narrow overall spatial disparities in the short run.

Further evidence from the spatial Markov chain analysis reveals pronounced path dependence and neighborhood effects in the evolution of coupling coordination. Specifically, regions with relatively high levels of coupling coordination exhibit strong temporal stability and are more likely to generate positive spillover effects on neighboring areas, whereas regions with low coordination levels tend to maintain their existing development states within spatial interactions. This spatial clustering pattern, characterized by “high–high” and “low–low” agglomerations, indicates that regional development does not proceed in isolation but is continuously reinforced or constrained through neighborhood relationships.

These findings are highly consistent with conclusions obtained in previous studies employing different research contexts and methodological frameworks. Chen et al. (2022) and Zhu et al. (2024), using spatial Markov chain approaches, demonstrate that the development level of neighboring regions significantly affects state transition probabilities, with high-level regions being more likely to form stable convergence clubs, while low-level regions exhibit a lower probability of cross-level transitions. Similarly, Liao et al. (2024) find that regional state transitions are largely concentrated around existing levels, with leapfrogging upgrades being relatively rare, thereby giving rise to distinct patterns of club convergence in spatial terms. Together, these studies underscore the critical role of spatial linkages and neighborhood effects in shaping long-term regional development trajectories.

From a longer-term perspective, low-level regions may become trapped in persistent low-equilibrium states or even development traps if they lack effective external support or cross-regional coordination. Diemer et al. (2022), in their analysis of European regional development, argue that "regional development traps" often arise from the combined effects of structural disadvantages and spatial isolation, which prevent lagging regions from achieving breakthroughs through internal adjustments alone. Likewise, Guevara-Rosero et al. (2025) show that poverty and low development levels exhibit strong spatial spillover characteristics, whereby low-level conditions in neighboring regions mutually reinforce each other and slow down overall improvement.

In the context of China, the spatial analysis conducted in this study suggests that the coupled evolution of new quality productive forces and high-quality economic development is shaped by similar mechanisms. High-level regions tend to reinforce their advantages through positive spatial spillovers, whereas low-level regions, in the absence of effective interregional linkages and external support, may remain locked in low-coordination states under the influence of path dependence. This spatially uneven structure further implies that relying solely on improvements within individual regions is likely to yield limited effects in promoting coordinated evolution. Instead, greater emphasis should be placed on regional collaboration and spatial linkage mechanisms to facilitate the diffusion of positive spillover effects.

Overall, the discussion highlights that the coupling coordination between new quality productive forces and high-quality economic development is a dynamic process jointly shaped by structural conditions, regional contexts, and spatial interactions. While productivity upgrading provides necessary conditions for high-quality development, its realized effects depend critically on the coordination among human capital, production facilities, and industrial structures, as well as on interregional spatial linkages and spillover effects. These findings suggest that advancing the coordinated evolution of new quality productive forces and high-quality economic development requires careful consideration of regional heterogeneity and spatial contexts, thereby avoiding overly simplified policy expectations.

6. Conclusion

Based on panel data for 30 provincial-level regions in China from 2013 to 2022, this study constructed comprehensive evaluation index systems for new quality productive forces and high-quality economic development. By integrating the entropy-weighted TOPSIS method, the coupling coordination degree model, and a set of complementary analytical tools—including Dagum Gini coefficient decomposition, kernel density estimation, and spatial Markov chain analysis—this study systematically examined the coupling coordination level, regional disparities, and dynamic evolution of the two systems from a spatiotemporal perspective. The core contribution of this research lies not in reiterating differences in levels or temporal trends, but in demonstrating that the coordinated advancement of the two systems is subject to pronounced structural and spatial constraints, with evolutionary paths jointly shaped by internal factor configurations and external spatial linkages.

At the aggregate level, the findings suggest that the coordinated evolution of new quality productive forces

and high-quality economic development does not occur spontaneously, but rather represents a long-term process conditioned by structural characteristics, institutional adaptation, and the efficiency of factor allocation. In a broader theoretical sense, this conclusion speaks directly to the literature on structural transformation and institutional evolution, which emphasizes that development quality depends on the alignment between technological progress, structural adjustment, and institutional environments (Wiegant et al., 2024; Grazini et al., 2024). In other words, while productivity upgrading provides a necessary foundation for high-quality development, its stable translation into development performance hinges on whether regional factor systems can achieve coordinated optimization and whether they can interact constructively with the surrounding spatial environment.

From a spatial and dynamic perspective, this study further shows that regional development is not an independent or linear process. Instead, it is characterized by path dependence, state persistence, and spatial interdependence, which may give rise to hierarchical evolution patterns and club agglomeration. This finding underscores the fundamental role of regional context in shaping long-term development trajectories and provides empirical support for the view that spatial interactions can either reinforce or inhibit regional transformation processes (Yang et al., 2024). Accordingly, differences in the coordinated evolution of new quality productive forces and high-quality economic development should not be attributed solely to short-term policy interventions or cyclical fluctuations, but rather understood as the outcome of enduring structural conditions and spatial relationships.

In terms of policy implications, the results do not support a uniform strategy aimed at improving isolated indicators. Instead, they highlight the importance of targeted coordination mechanisms and regionally differentiated interventions aligned with the structural characteristics identified in the empirical analysis. For regions trapped in low-level coordination states—particularly those exhibiting "low–low" spatial clustering—priority should be given to overcoming structural bottlenecks in the means of production subsystem, including deficiencies in advanced production facilities, digital infrastructure, and technological integration capacity. Strengthening these foundational conditions is essential for breaking path dependence and facilitating upward state transitions. For regions already at relatively high coordination levels, policy efforts should focus on preventing structural lock-in and enhancing outward spillover capacity. This can be achieved by promoting cross-regional innovation diffusion, improving interregional industrial linkages, and establishing institutional mechanisms that facilitate the transmission of productivity gains to neighboring areas. Differentiated and tiered policy frameworks—based on subsystem constraints and spatial transition characteristics—are more likely to mitigate persistent divergence and promote sustainable coordinated development across regions.

Several limitations of this study should be acknowledged. First, the measurement of new quality productive forces relies primarily on macro-level statistical indicators. While this approach captures regional-level characteristics in a comprehensive manner, it is less capable of reflecting micro-level technological breakthroughs, organizational transformations, and firm-level behavioral heterogeneity. Second, the province-level analytical framework may obscure important variations within provinces, such as differences among urban agglomerations, metropolitan areas, and industrial sectors, thereby limiting a more nuanced understanding of intra-regional heterogeneity. Third, although this study focuses on descriptive characterization and dynamic evolution of coupling coordination, the causal mechanisms underlying these relationships warrant further investigation. Future research could build on this study by employing finer-grained data and adopting empirical strategies with stronger identification power to more rigorously uncover the mechanisms linking new quality productive forces and high-quality economic development. In addition, further exploration of spatial channels—such as industrial linkages, factor mobility, and policy diffusion—would help clarify how spatial interactions shape coordinated evolution across regions, thereby providing more targeted empirical evidence to support more balanced and sustainable regional high-quality development.

Funding: *Suqian Social Science Research Project (25SYT-11)*

Reference

Amankwah-Amoah, J., Bai, Y., Liu, L., Wang, S., & Zhang, H. (2025). Bridging the gap: how transport infrastructure reduces bilateral trade costs to fuel GDP growth. *Journal of Chinese Economic and Business Studies*, 23(2), 295-320. https://doi.org/10.1080/14765284.2025.2472502

Benatti, N., Groiss, M., Kelly, P., & Lopez-Garcia, P. (2024). Environmental regulation and productivity growth in the euro area: Testing the porter hypothesis. *Journal of Environmental Economics and Management*, 126, 102995. https://doi.org/10.1016/j.jeem.2024.102995

Chen, H., Hu, S., & Cai, Y. (2024). Driving effect of fintech on firm green innovation in China's strategic emerging industries: The mediating role of digital transformation. *International Review of Economics & Finance*, 96, 103613. https://doi.org/10.1016/j.iref.2024.103613

Chen, S., Peng, C., Zhang, M., & Chen, P. (2022). Club Convergence and Spatial Effect on Green Develo -pment of the Yangtze River Economic Belt in China with Markov Chains Approach. *Land*, 11(1), 143. https://doi.org/10.3390/land11010143

Chen, Z., & Xing, R. (2025). Digital economy, green innovation and high-quality economic development. *International Review of Economics & Finance*, 99, 104029. https://doi.org/10.1016/j.iref.2025.104029

Chu, H., Niu, X., Li, M., & Wei, L. (2025). Research on the impact of new quality productivity on enterprise ESG performance. *International Review of Economics & Finance*, 99, 104009. https://doi.org/10.1016/j.iref.2025.104009

Dagum, C. (1997). A new approach to the decomposition of the gini income inequality ratio. *Empirical Economics*, 22(4), 515-531. https://doi.org/10.1007/BF01205777

Dai, D., & Zheng, Y. (2025). The New Quality Productive Force, Science and Technology Innovation, and Optimization of Industrial Structure. *Sustainability*, 17(10), 4439. https://doi.org/10.3390/su17104439

Degirmenci, T., Aydin, M., Bozatli, O., & Ahmed, Z. (2025). Consolidating Sustainable Development in OECD Countries: The Role of Green Energy Transition, Green Innovation, Environmental Policy Stringency, and Human Capital. *Sustainable Development*. https://doi.org/10.1002/sd.70034

Diemer, A., Iammarino, S., Rodríguez-Pose, A., & Storper, M. (2022). The regional development trap in Europe. *Economic Geography*, 98(5), 487-509. https://doi.org/10.1080/00130095.2022.2080655

Feng, N., Yan, M., & Yan, M. (2024). Spatiotemporal evolution and influencing factors of new-quality productivity. *Sustainability*, 16(24), 10852. https://doi.org/10.3390/su162410852

Gao, Z., Li, L., & Hao, Y. (2024). Resource industry dependence and high-quality economic development of Chinese style: Reexamining the effect of the "Resource Curse". *Structural Change and Economic Dynamics*, 68, 1-16. https://doi.org/10.1016/j.strueco.2023.09.013

Geng, K., Zhang, X., Jiang, H., & Zhuang, Z. (2024). The spatio-temporal characteristics and dynamic evolution of coupling and coordinated development of innovation factor allocation and green economy in China. *Frontiers in Environmental Science*, 12, 1475508. https://doi.org/10.3389/fenvs.2024.1475508

Glawe, L. (2025). Nonlinearities in the institutions-growth relationship in a dynamic panel data framework: Evidence from China's provinces. *China Economic Review*, 102583. https://doi.org/10.1016/j.chieco.2025.102583

Grazini, C., Guarini, G., & Porcile, J. G. (2024). Institutional change and ecological structural change. *Structural Change and Economic Dynamics*, 71, 354-368. https://doi.org/10.1016/j.strueco.2024.08.004

Guevara-Rosero, G. C., Vizuete-Salazar, Y., Loza-Aguirre, E., & Ramírez-Álvarez, J. (2025). Local Governments and Poverty and Spatial Spillovers of Poverty in Ecuador: GC Guevara-Rosero et al. *Applied Research in Quality of Life*, 1-37. https://doi.org/10.1007/s11482-025-10454-w

He, J., Chen, Y., Chen, H., Zhao, J., Wang, C., & Xu, L. (2025). Sci-Tech finance, digital economy and high-quality development of regional economy: empirical evidence from 273 cities in China. *Humanities and Social Sciences Communications*, 12(1), 1-16. https://doi.org/10.1057/s41599-025-05033-1

Hosseinioun, M., Neffke, F., Zhang, L.,& Youn, H. (2025).Skill dependencies uncover nested human capital. *Nature Human Behaviour*, 1-15. https://doi.org/10.1038/s41562-024-02093-2

Hou,G.,Sun,C.,& Lu,Z. (2025).Business environment and its impact on high-quality economic development: A configurational analysis of enhancement pathways. *PloS one*, 20(1), e0302508. https://doi.org/10.1371/journal.pone.0302508

Hu, Y., & Jia, X. (2025). Empowering the Intelligent Transformation of the Manufacturing Sector Through New Quality Productive Forces:Value Implications,Theoretical Analysis and Empirical Examination. *Sustainability*, 17(15), 7006. https://doi.org/10.3390/su17157006

Huang, J., Tian, Y., Khanal, R., Wen, F., & Deng, C. (2022). Evaluation and prediction of high-quality development in China: A time-spatial analysis from Hubei province.*Frontiers in Environmental Science*, 10, 987188. https://doi.org/10.3389/fenvs.2022.987188

Jiang, S. (2025).Evaluation of new quality productive forces in Henan province based on improved entropy weight-TOPSIS method and deep learning. *Scientific Reports*, 15(1), 35434. https://doi.org/10.1038/s41598-025-19

309-8

Jin, G., Wang, G., Li, W., Sheng, H., Hu, C., & Zhao, Y. (2025). The impact of environmental regulation on carbon emissions and its mechanisms in Chinese cities. *Scientific Reports*, 15(1), 41665. https://doi.org/10.1038/s41598-025-25556-6

Kafouros, M., Aliyev, M.,Piperopoulos, P., Au, A. K. M., Ho, J. W. Y., & Wong, S. Y. N.(2024). The role of institutional quality and industry dynamism in explaining firm performance in emerging economies. *Global Strategy Journal*, 14(1), 56-83. https://doi.org/10.1002/gsj.1479

Lah, O. (2025).Breaking the silos:integrated approaches to foster sustainable development and climate action. *Sustainable Earth Reviews*, 8(1), 1. https://doi.org/10.1186/s42055-024-00102-w

Lei, X., Zhao, W., & Du, H. (2025). Study on the impact of new quality productive forces on agricultural green production efficiency. *Scientific Reports*, 15(1), 20652. https://doi.org/10.1038/s41598-025-06980-0

Li, C., & Wang, M. (2025). Industrial upgrading and new quality productive forces: evidence from Chinese industrial parks. *Frontiers in Public Health*, 13, 1683019. https://doi.org/10.3389/fpubh.2025.1683019

Liang, H., & Huang, W. (2025). Technological Innovation Spurring New Quality Productive Forces and Its Global Effect. *China Finance and Economic Review*, 14(1), 50-69. https://doi.org/10.1515/cfer-2025-0003

Liao, Z., Liang, S., & Wang, X. (2024). Spatio-temporal evolution and driving factors of green innovation efficiency in the Chinese urban tourism industry based on spatialMarkov chain. *Scientific Reports*, 14(1), 10671. https://doi.org/10.1038/s41598-024-61226-9

Lin, L., Gu, T., & Shi, Y. (2024). The Influence of New Quality Productive Forces on High-Quality Agricultural Development in China: Mechanisms and Empirical Testing. *Agriculture*, 14(7), 1022. https://doi.org/10.3390/agriculture14071022

Liu, T., & Shen, W. (2025). Regional differences, spatial temporal evolution and dynamic evolution of food security in China. *Scientific Reports*, 15(1), 35180. https://doi.org/10.1038/s41598-025-19108-1

Liu, Y., Duan, D., & Feng, Z. (2025a). The Impact of New Quality Productive Forces on the High-Quality Development of China's Foreign Trade. *Systems*, 13(5), 367. https://doi.org/10.3390/systems13050367

Liu, Y., & He, Z.(2024).Synergistic industrial agglomeration, new quality productive forces and high-quality development of the manufacturing industry. *International Review of Economics & Finance*, 94, 103373. https://doi.org/10.1016/j.iref.2024.103373

Liu, Z., Xiang, W., Wang, J., Chen, W., & Zhou, Y.(2025b).Spatiotemporal patterns and regional disparities in the coupling and coordination between green finance and ecological environment in China. *Frontiers in Environmental Science*, 13, 1508830. https://doi.org/10.3389/fenvs.2025.1508830

Liu, Z., Zhang, H., Guo, C., & Yang, Y. (2025c). New Quality Productive Forces Enabling High-Quality Development: Mechanism, Measurement, and Empirical Analysis. *Sustainability*, 17(18), 8146. https://doi.org/10.3390/su17188146

Lu, M.(2025).How new quality productivity drives china's sustainable development: Evidence from dynamic indicator evolution. *PloS one*, 20(12), e0338804. https://doi.org/10.1371/journal.pone.0338804

Nguyen, P. H.,Van Nguyen, D.,Nguyen, T. P.,Nguyen, L. A. T., Nguyen, T. H. T., Vu, T. G., & Le Hoang, H. G. (2025). Income-dependent variations in innovation performance: insights from sustainable economic development indicators. *Journal of Open Innovation: Technology, Market, and Complexity*, 11(1), 100478. https://doi.org/10.1016/j.joitmc.2025.100478

Norgaard, R. B. (1990). Economic indicators of resource scarcity: a critical essay. *Journal of Environmental Economics and Management*, 19(1), 19-25. https://doi.org/10.1016/0095-0696(90)90057-6

Okolo,C.V., Susaeta,A., & Okorie,D. I. (2025). On the relationship between internet usage and technological innovation: Insight from world panel data. *Sustainable Futures*, 9, 100403. https://doi.org/10.1016/j.sftr.2024.100403

Sharma, M., Vadalkar, S., Antony, R., Chavan, G., & Tsagarakis, K. P. (2024). Can Industry 4.0-enabled smart manufacturing help firms in emerging economies move toward carbon-neutrality?. *Computers & Industrial Engineering*, 192, 110238. https://doi.org/10.1016/j.cie.2024.110238

Shi, Y., Liu, X., & Zhang, J.(2025). A dynamic QCA of new quality productivity driving high quality economic development in the yellow river basin. *Scientific Reports*, 15(1), 41565. https://doi.org/10.1038/s41598-025-25502-6

Shin, J., Amaral, M., Barros, A. C., & Morgan, M. G.(2025). How does general andspecific human capital drive technology development in firms?. *PLoS One*, 20(11), e0337056. https://doi.org/10.1371/journal.pone.

Tsangaris, S., Xepapadeas, A., Yannacopoulos, A. N., & Salvati, L. (2024).Spatial externalities, R&D spillovers, and endogenous technological change. *Regional Science and Urban Economics*, 109, 104055. https://doi.org/10.1016/j.regsciurbeco.2024.104055

Wan, J., Xie, Q., & Fan, X. (2024). The impact of transportation and information infrastructure on urban productivity: Evidence from 256 cities in China. *Structural Change and Economic Dynamics*, 68, 384-392. https://doi.org/10.1016/j.strueco.2023.11.008

Wiegant, D., Dewulf, A., & Van Zeben, J. (2024). Alignment mechanisms to effectively govern the sustain-

able development goals. *World Development*, 182, 106721. https://doi.org/10.1016/j.worlddev.2024.106721

Wolf, C. (2025). The making and unmaking of uneven development: the role of anchor firms in creating and overcoming industrial decline in East Germany. *Journal of Economic Geography*, lbaf055. https://doi.org/10.1093/jeg/lbaf055

Xiao, J., Wang, X., Li, G., Li, H., & Nie, S. (2025).Spatial-Temporal Coupling Mechanism and Influencin Factors of New-Quality Productivity, Carbon Emission Reduction and High-Quality Economic Development.*Sustainability*, 17(21), 9715. https://doi.org/10.3390/su17219715

Xu, L.,Tanamee, D., & Romprasert, S.(2025). Does Digital Village Construction Promote Agricultural Green Total Factor Productivity? An Empirical Study Based on China's Provincial Panel Data. *Economies*, 13(4), 85. https://doi.org/10.3390/economies13040085

Yang, L., Zhang, Y., Huo, B., & Tian, M. (2025).The impact of digital transformation on new quality productivity: a moderating analysis based on the socio-technical system theory. *Industrial Management & Data Systems*, 125(12), 3179-3198. https://doi.org/10.1108/IMDS-08-2024-0767

Yang, W., Huang, R., & Li, D. (2024). China's high-quality economic development: A study of regional variations and spatial evolution. *Economic Change and Restructuring*, 57(2), 86. https://doi.org/10.1007/s10644-024-09676-z

Zhang, J., & Liu, Y. (2025).How Does Digital Innovation Empower the Development of New Quality Productive Forces? An Empirical Study Based on Double Machine Learning. *Sustainability*, 17(6), 2652. https://doi.org/10.3390/su17062652

Zheng, C., Zheng, Z., Tian, L., & Han, S. (2025). New Quality Productive Forces Enable the High-Quality Development of Energy Enterprises. *International Studies of Economics*. https://doi.org/10.1002/ise3.70015

Zhou, G., Zhang, Z., & Fei, Y. (2022). How to evaluate the green and high-quality development path? An FsQCA approach on the China pilot free trade zone. *International Journal of Environmental Research and Public Health*, 19(1), 547. https://doi.org/10.3390/ijerph19010547

Zhu, H., Jiang, S., & Zhao, X. (2024). Spatial-temporal evolution and determinants of green economy efficiency:an integrated analytical approach. *Sustainable Futures*, 8, 100359. https://doi.org/10.1016/j.sftr.2024.100359

To cite this article: Jimmy Lim Siau Shiong. (2026). *Board Independence, Audit Quality and Financial Performance with the Mediating Role of Technological Innovation in China, Journal of Financial and Economic Dynamics*, 1(1),89-113;https://doi.org/10.66361/jfed.55

Board Independence, Audit Quality and Financial Performance with the Mediating Role of Technological Innovation in China

Jimmy lim Siau Shiong
Office of the President Northern Kuala Lumpur International College (NKL, formerly Pintar College)Unit 01-01, United Point, 10, Jalan Lang Emas, Taman Segambut Aman, Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia
** Correspondence: Jimmy lim Siau Shiong,jimmy@nkl.edu.my*

Abstract: This study examines the relationships among corporate governance, audit quality, technological innovation, and financial performance in Chinese accounting firms, with particular emphasis on the mediating role of technological innovation. Grounded in agency theory and the resource-based view (RBV), the study develops an integrated framework to explain how governance mechanisms influence firm performance in a digitally evolving environment. Corporate governance is proxied by board independence, while audit quality is measured using firm-level audit characteristics, and technological innovation is captured through R&D intensity and digital investment indicators. Using panel data of 420 firm-year observations, the study employs fixed-effects regression and bootstrapped mediation analysis to test the proposed relationships. The results indicate that both board independence and audit quality are positively associated with financial performance. In addition, corporate governance and audit quality significantly promote technological innovation. Mediation analysis reveals that technological innovation partially mediates the relationships between corporate governance, audit quality, and financial performance, suggesting that governance mechanisms influence performance both directly and indirectly through technological capabilities. This study contributes to the corporate governance and accounting literature by highlighting the complementary role of technological innovation in enhancing governance effectiveness. The findings provide practical implications for accounting firms and policymakers, emphasising the importance of aligning governance reforms with digital transformation strategies to improve firm performance and long-term competitiveness.
Key Words:Board Independence;Audit Quality; Financial Performance; Mediating Role; Technological Innovation;

1.Introduction

1.1 Background of the Study

Corporate governance plays a fundamental role in shaping organisational behaviour, safeguarding stakeholder interests, and enhancing firm performance. Effective governance mechanisms mitigate agency conflicts between managers and shareholders, promote transparency, and strengthen accountability within firms. In the accounting profession, where public trust, professional judgment, and information credibility are paramount, the quality of corporate governance is especially critical. Weak governance structures in accounting firms can undermine audit quality, distort financial reporting, and ultimately erode investor confidence and market stability.

Audit quality constitutes a central pillar of corporate governance in accounting firms. High-quality audits improve the reliability of financial statements, reduce information asymmetry, and enhance corporate credibility in capital markets. Conversely, audit failures can trigger severe economic and reputational consequences, particularly in emerging markets where institutional frameworks and regulatory enforcement are still evolving. In China, despite continuous regulatory reforms aimed at strengthening corporate

governance and audit supervision, concerns persist regarding audit independence, professional competence, and governance effectiveness in accounting firms. High-profile financial misstatements and audit scandals have further intensified scrutiny of governance practices within the profession.

Simultaneously, rapid technological advancement has profoundly transformed the accounting and auditing landscape. Technologies such as artificial intelligence, blockchain, big data analytics, and cloud-based systems have reshaped audit methodologies, risk assessment processes, and internal control mechanisms. Technological innovation enables accounting firms to enhance audit precision, improve operational efficiency, and strengthen compliance and monitoring functions. Beyond operational benefits, technological innovation increasingly serves as a strategic resource that supports governance effectiveness by facilitating information transparency, real-time monitoring, and data-driven decision-making.

Despite the growing importance of technological innovation, existing research largely treats corporate governance, audit quality, and technological innovation as independent determinants of firm performance. Limited attention has been paid to the interaction between governance mechanisms and technological innovation, particularly the extent to which innovation enhances or channels the effectiveness of governance practices. This gap is especially evident in studies focusing on accounting firms, where technological adoption directly influences audit quality and governance outcomes.

The governance of the Chinese institutional environment is different from the other economies in the West. In China, corporate governance is characterized by concentrated ownership structures, heavy involvement from state authorities, and evolving regulatory enforcement mechanisms (Jiang & Kim, 2015). In many companies, dominant shareholders have considerable power over the firm and this may make formal governance like board independence less effective. Regulatory enforcement varies by region, leading to differences in audit quality and governance practices. Other than that, managerial decision-making is often influenced by relational dynamics (guanxi) and informal networks, which hampers formal governance frameworks. In other words, technological innovation can strengthen governance through enhanced transparency, standardisation of processes and reduction in subjective discretion.

The Chinese context offers a unique setting for examining these relationships. China's accounting firms operate within an institutional environment characterised by concentrated ownership structures, evolving regulatory oversight, and rapid digital transformation. While governance reforms and technological investments have accelerated in recent years, the effectiveness of these initiatives in improving financial performance remains an empirical question. Understanding whether technological innovation strengthens the link between corporate governance, audit quality, and financial performance is therefore of both theoretical and practical significance.

Against this background, this study investigates the relationships among corporate governance, audit quality, technological innovation, and financial performance in Chinese accounting firms. Specifically, it examines whether technological innovation mediates the effects of corporate governance and audit quality on financial performance. By adopting an integrated analytical framework, this research contributes to a deeper understanding of how governance mechanisms translate into performance outcomes in a technologically evolving accounting environment.

1.2 Problem Statement

Although corporate governance has been extensively examined in the finance and accounting literature, empirical findings regarding its impact on firm performance remain inconsistent. Studies report mixed evidence on the effectiveness of governance mechanisms such as board independence and audit quality, particularly in emerging economies. These inconsistencies suggest that corporate governance alone may not be sufficient to explain variations in firm performance and that additional organisational or contextual factors may influence governance effectiveness.

In the accounting sector, the problem is further compounded by the critical role of audit quality. While audit quality is widely recognised as a key governance mechanism that enhances financial reporting reliability and investor confidence, its impact on firm performance is not always straightforward. In some cases, stricter audit controls may increase compliance costs without generating proportional performance gains. In others, weak

audit oversight can expose firms to reputational damage and regulatory sanctions. In China, despite strengthened governance regulations, accounting firms continue to face challenges related to audit independence, professional standards, and uneven enforcement across regions.

At the same time, technological innovation has emerged as a powerful force reshaping the accounting profession. Investments in digital technologies are expected to improve audit efficiency, strengthen internal controls, and enhance governance transparency. However, empirical research has not sufficiently clarified whether technological innovation directly improves financial performance or whether its value lies in reinforcing existing governance mechanisms. Most prior studies treat technological innovation as an independent driver of performance, overlooking its potential role as an enabling or mediating mechanism within corporate governance frameworks.

This gap is particularly evident in the context of Chinese accounting firms. While China has experienced rapid technological advancement and digital transformation, the extent to which technological innovation enhances the effectiveness of corporate governance and audit quality remains underexplored. Existing studies rarely examine whether technological innovation serves as a transmission channel through which governance mechanisms influence financial performance. As a result, the mechanisms linking governance practices, audit quality, and financial outcomes remain inadequately understood.

Furthermore, China's distinctive institutional environment intensifies this research problem. The coexistence of strong regulatory intervention, ownership concentration, and rapid technological adoption creates a complex governance landscape. Governance reforms alone may be insufficient to improve performance if they are not supported by appropriate technological capabilities. Conversely, technological investments may fail to generate value if governance structures are weak or ineffective. Understanding the interdependence between governance and technological innovation is therefore essential for explaining performance outcomes in Chinese accounting firms.

Given these unresolved issues, there is a clear need for empirical research that integrates corporate governance, audit quality, and technological innovation within a unified analytical framework. This study addresses this need by examining the mediating role of technological innovation in the relationship between corporate governance, audit quality, and financial performance in Chinese accounting firms. By doing so, it seeks to clarify how governance mechanisms operate in a technologically dynamic environment and to provide more robust explanations for performance differences within the accounting sector.

1.3 Research Questions

To achieve the objectives of this study, the following research questions are formulated:

- To what extent do corporate governance practices influence the financial performance of accounting firms in China?
- Does audit quality significantly affect the financial performance of Chinese accounting firms?
- Does technological innovation mediate the relationship between corporate governance and financial performance?
- Does technological innovation mediate the relationship between audit quality and financial performance?

1.4 Research Objectives

The primary objective of this study is to examine how corporate governance and audit quality influence financial performance, with particular emphasis on the mediating role of technological innovation in Chinese accounting firms.

The specific objectives are to:

- Examine the relationship between corporate governance practices and financial performance in Chinese accounting firms.
- Investigate the impact of audit quality on financial performance.
- Analyse the mediating effect of technological innovation on the relationship between corporate governance and financial performance.
- Examine whether technological innovation mediates the relationship between audit quality and financial performance.

1.5 Significance of the Study

This study makes several important contributions to the literature on corporate governance, auditing, and technological innovation, particularly within the context of emerging economies. First, it extends corporate governance research by integrating technological innovation as a mediating mechanism between governance practices and financial performance. While prior studies have predominantly examined corporate governance, audit quality, and technological innovation as independent determinants of firm performance, this study offers a more nuanced explanation by demonstrating how technological innovation functions as a transmission channel through which governance mechanisms influence financial outcomes.

Second, this study contributes to the accounting and auditing literature by providing empirical evidence from Chinese accounting firms, a context that remains underrepresented in existing research. Given the critical role of audit quality in ensuring financial reporting credibility, the findings enhance understanding of how governance structures and audit practices operate in environments characterised by concentrated ownership, evolving regulatory frameworks, and uneven institutional enforcement. By focusing on accounting firms, this study sheds light on governance-performance dynamics within a profession where trust, independence, and information reliability are fundamental.

Third, from a theoretical perspective, the study enriches corporate governance theory by bridging governance mechanisms with innovation-based perspectives. By highlighting the mediating role of technological innovation, the findings support the view that governance effectiveness depends not only on formal structures but also on firms' technological capabilities. This integrated perspective provides a more comprehensive explanation of performance variation and advances theoretical discussions on the interaction between governance and innovation.

From a practical standpoint, the study offers valuable insights for regulators, policymakers, and practitioners. The findings suggest that governance reforms and audit quality improvements are more likely to translate into superior financial performance when supported by technological innovation. For accounting firm managers, the results underscore the importance of aligning governance structures with digital transformation strategies. For policymakers, the study provides evidence to support regulatory initiatives that promote both governance effectiveness and technological adoption. Overall, this research contributes to more informed decision-making and supports the sustainable development of the accounting profession in technologically dynamic environments.

2. Literature Review

2.1 Corporate Governance and Firm Performance

Corporate governance constitutes the foundational framework through which firms are directed, monitored, and controlled. It establishes the allocation of rights and responsibilities among shareholders, boards of directors, and management, thereby shaping decision-making processes and organisational outcomes. The primary objective of corporate governance is to mitigate agency conflicts arising from the separation of ownership and control, enhance transparency, and promote accountability, ultimately improving firm performance. From the perspective of agency theory, corporate governance mechanisms are designed to reduce opportunistic behaviour by managers and align managerial actions with shareholder interests (Jensen & Meckling, 1976). Governance tools such as board oversight, independent directors, and monitoring systems reduce agency costs by constraining self-serving managerial decisions and improving the efficiency of resource allocation. Empirical evidence from developed economies generally supports a positive relationship between strong governance practices and firm performance, as measured by profitability, market valuation, and operational efficiency (Brown & Caylor, 2009; Black et al., 2012).

However, the governance–performance relationship is far from uniform. Numerous studies report mixed or inconclusive findings, suggesting that governance mechanisms do not exert a universally positive effect across institutional contexts. For example, Wintoki et al. (2012) argue that the effectiveness of governance structures is contingent on firm-specific and environmental factors, including ownership concentration, regulatory enforcement, and market maturity. In some cases, excessive monitoring may constrain managerial flexibility, hinder strategic decision-making, and reduce performance. These complexities are particularly evident in

emerging economies. Weak legal enforcement, concentrated ownership structures, and institutional voids may limit the effectiveness of formal governance mechanisms. In China, corporate governance operates within a unique institutional framework characterised by strong state influence, concentrated shareholding, and evolving regulatory oversight. Although governance reforms have strengthened formal board structures and disclosure requirements, the effectiveness of these mechanisms in enhancing firm performance remains subject to debate.

Within the accounting sector, the governance–performance relationship is especially critical. Accounting firms rely heavily on reputation, professional credibility, and information integrity. Weak governance can undermine audit quality, damage trust, and expose firms to regulatory and reputational risks. Accordingly, understanding how corporate governance influences performance in accounting firms requires a context-sensitive approach that considers both institutional constraints and complementary organisational capabilities.

Recent research increasingly highlights the impact of technological innovation and digital transformation on corporate governance outcomes. To illustrate, Chen et al. (2020) note that board-level technological expertise enhances firm performance in digitally intensive settings. Claessens and Yurtoglu (2013) and more recent extensions similarly suggest that the effectiveness of governance in emerging markets depends on institutional development and technology.

In the audit context, DeFond and Zhang (2020) examine the concept of audit quality. At the same time, they support the significance of data analytics and digital tools in our audit. Above all, they help enhance audit reliability in auditing. The above developments suggest that we need to supplement conventional governance techniques with technology to stay relevant in a modern organisation.

According to recent studies, it is digital transformation and technological capabilities that increasingly shape corporate governance, especially in developing countries. Research evidence indicates that the effectiveness of governance is enhanced by the incorporation of digitally-related technologies and systems by firms into their governance (Chen, Chen, & Lin, 2023). Furthermore, elements of corporate governance may interact with technology capabilities to create firm performance whilst, at the same time, the effective governance of organizations may be influenced by institutional and technology factors (Alabdullah, 2023).

2.2 Audit Quality as a Governance Mechanism

Audit quality represents a central component of corporate governance, particularly within accounting firms. High-quality audits enhance the reliability of financial reporting, reduce information asymmetry, and reinforce investor confidence. From an agency theory perspective, auditing serves as an external monitoring mechanism that constrains managerial opportunism and aligns managerial actions with shareholder interests (DeAngelo, 1981).

Prior research highlights the economic consequences of audit quality. High audit quality is associated with lower earnings management, improved financial reporting credibility, reduced cost of capital, and enhanced firm value (Francis & Michas, 2013; Lennox & Li, 2020). For accounting firms themselves, audit quality is not only an internal governance issue but also a determinant of market reputation and long-term competitiveness. Audit failures can lead to regulatory sanctions, litigation risk, and reputational damage, directly affecting firm performance.

In China, audit quality has attracted increasing regulatory and academic attention due to historical weaknesses in the auditing profession. Although regulatory authorities have introduced stricter audit standards and oversight mechanisms, challenges persist regarding auditor independence, professional competence, and consistency of audit practices across regions. The dominance of large clients, ownership concentration, and institutional pressures may compromise auditor objectivity, reducing the effectiveness of audit quality as a governance mechanism. Empirical findings on the relationship between audit quality and firm performance in China remain mixed. Some studies document positive performance effects associated with higher audit quality, while others find limited or insignificant impacts due to institutional constraints. These mixed results suggest that audit quality alone may not be sufficient to enhance firm performance unless supported by complementary governance structures and organisational capabilities.

The concept of audit quality is gradually changing with literature focusing on the role of digital technologies and data analytics in recent papers. According to studies, the use of innovative audit technology enhances audit efficiency, risk assessment capability, and the reliability of financial reporting (Appelbaum; Kogan; Vasarhelyi; Yan, 2023). Moreover, high audit quality enhances transparency and firm value. However, its interaction with innovation activities is not that clear (Lennox & Li, 2020; DeFond & Zhang, 2020).

2.3 Technological Innovation and Firm Performance

Technological innovation has emerged as a key driver of organisational competitiveness, productivity, and performance. Innovation encompasses investments in research and development, adoption of advanced technologies, and the implementation of new processes and services. In the accounting profession, technological advancements such as artificial intelligence, blockchain, big data analytics, and cloud computing have fundamentally transformed audit methodologies, risk assessment, and internal control systems.

From the resource-based view (RBV), technological innovation constitutes a strategic resource that can generate sustainable competitive advantage when it is valuable, rare, difficult to imitate, and non-substitutable (Barney, 1991). Empirical studies generally support a positive relationship between innovation and firm performance, particularly in knowledge-intensive and professional service industries. Technological adoption enables firms to improve efficiency, enhance service quality, and respond more effectively to regulatory and market demands.

However, technological innovation does not automatically translate into superior financial performance. Innovation investments involve significant costs, uncertainty, and implementation challenges. Without effective governance and strategic alignment, technological initiatives may increase operational complexity, expose firms to cybersecurity risks, and fail to deliver expected performance gains. This suggests that the performance effects of innovation are contingent upon firms' governance structures and managerial capabilities.

In accounting firms, technological innovation plays a dual role. On the one hand, it enhances audit quality by improving data accuracy, audit coverage, and risk detection. On the other hand, it supports governance transparency and monitoring by enabling real-time information flows and data-driven decision-making. As such, technological innovation represents both an operational and governance-related capability.

Technological innovation remains a key factor in improving firm performance and governance efficiency. Recent research studies show that digital transformation and innovation capabilities enhance firms' operations efficiency and decision-making processes (Verhoef et al., 2021; Nambisan, Lyytinen, Majchrzak, & Song, 2017). More recent evidence has shown that artificial intelligence and the use of big data analysis are reinventing the auditing industry and strengthening internal controls (Appelbaum et al., 2023).

2.4 Linking Corporate Governance and Technological Innovation

Recent literature increasingly recognises the interdependence between corporate governance and technological innovation. Governance mechanisms shape managerial incentives, strategic priorities, and risk-taking behaviour, all of which are central to innovation outcomes. Boards with effective oversight and diverse expertise are better positioned to support long-term innovation investments and manage the risks associated with technological change.

Agency theory suggests that governance mechanisms can mitigate managerial risk aversion and short-termism, thereby encouraging innovation-oriented investments. At the same time, resource dependence theory emphasises the role of boards in providing access to external knowledge, expertise, and networks that support innovation activities. Empirical evidence indicates that board characteristics and ownership structures significantly influence firms' R&D intensity, patent output, and innovation efficiency (Chen et al., 2015; Amore & Failla, 2020).

In China, governance structures may exert a particularly strong influence on innovation due to concentrated ownership and state involvement. Governance mechanisms affect resource allocation decisions and the extent

to which firms pursue technological upgrading. These findings suggest that technological innovation may function as an intermediary mechanism through which governance practices influence firm performance.

2.5 Technological Innovation as a Mediating Mechanism

Despite growing interest in governance and innovation, limited research has explicitly examined technological innovation as a mediating mechanism between corporate governance and firm performance. Most prior studies treat innovation as either an independent predictor or a direct outcome of governance practices, overlooking its potential role as a transmission channel.

Mediation theory suggests that governance mechanisms influence performance indirectly by shaping firms' innovation capabilities. Effective governance improves oversight, strategic alignment, and resource allocation, thereby fostering innovation, which in turn enhances performance. Empirical evidence supporting such mediation effects has begun to emerge, particularly in studies examining ownership structure and firm performance (Qin et al., 2019; Peng & Zhang, 2022).

In the context of accounting firms, this mediating role is especially relevant. Technological innovation enhances audit quality, strengthens internal controls, and improves governance transparency, suggesting that innovation amplifies the effectiveness of governance mechanisms. Accordingly, examining technological innovation as a mediating variable provides a more comprehensive understanding of how corporate governance and audit quality translate into financial performance.

As the digital transformation continues to gain pace, recent studies are increasingly reflecting the need for linking corporate governance with technology innovation. For example, Alabdullah (2023) shows that governance mechanisms impact firm performance through innovation capability in emerging markets. In the same vein, Zhang et al. (2023) claim that through transparency and more efficient decision-making, digital transformation enhances the effectiveness of governance structures.

Data analytics and AI use enhances the reliability and quality of an audit (Appelbaum et al., 2023). In addition, article Liu et al. (2024) state that technological innovation mediates the relationship between governance mechanisms and firm performance in knowledge-intensive industries. The recent findings emphasize the unified analytical approach for analysis of governance and innovation.

New real-world findings show that technological innovation mediates the relationship between governance mechanisms and firm performance. Research shows governance structures impact firm performance indirectly through innovation capability and digital transformation (Alabdullah, 2023). Therefore, technological innovation is an important transmission mechanism through which governance enhances organisational outcomes, especially in knowledge-based and service-oriented industries.

2.6 Hypothesis Development

Corporate Governance and Financial Performance

Based on agency theory and prior empirical evidence, effective corporate governance is expected to enhance firm performance by reducing agency costs and improving monitoring efficiency.

H1: Corporate governance practices are positively associated with the financial performance of Chinese accounting firms.

Audit Quality and Financial Performance

Audit quality serves as a critical governance mechanism that enhances reporting reliability and firm credibility, thereby improving performance outcomes.

H2: Audit quality is positively associated with the financial performance of Chinese accounting firms.

Mediating Role of Technological Innovation

From an RBV perspective, technological innovation represents a strategic capability that enables governance mechanisms to translate into performance gains. Effective governance and high audit quality are expected to foster technological adoption, which in turn enhances financial performance.

H3: Technological innovation mediates the relationship between corporate governance and financial performance in Chinese accounting firms.

H4: Technological innovation mediates the relationship between audit quality and financial performance in Chinese accounting firms.

2.7 Conceptual Framework

Based on the literature review and hypothesis development, this study proposes a conceptual framework in which corporate governance and audit quality influence financial performance both directly and indirectly through technological innovation. This framework integrates governance theory and innovation-based perspectives to explain performance outcomes in Chinese accounting firms operating in a technologically dynamic environment.

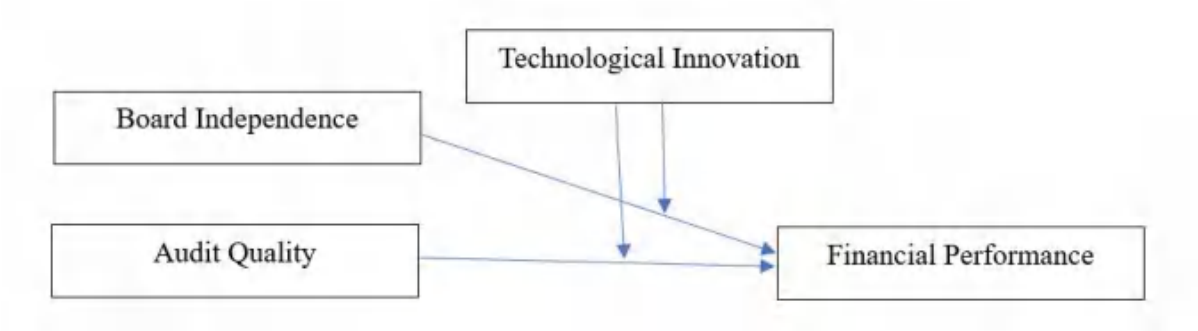


Diagram 1 Conceptual Framework

3. Research Methodology

3.1 Research Design

This study adopts a quantitative research design to examine the relationships among corporate governance, audit quality, technological innovation, and financial performance in Chinese accounting firms. A quantitative approach is appropriate given the study's objective of testing theoretically grounded hypotheses and identifying statistically significant relationships among variables. Consistent with prior corporate governance and accounting research, this study employs secondary data and econometric analysis to provide robust empirical evidence. The research framework is grounded in agency theory and the resource-based view (RBV), which jointly explain how governance mechanisms and technological capabilities influence organisational performance. In particular, the study examines whether technological innovation functions as a mediating mechanism through which corporate governance and audit quality affect financial performance. A mediation-based analytical framework is therefore adopted to capture both direct and indirect effects.

3.2 Sample Selection and Data Sources

The empirical analysis focuses on Chinese accounting firms operating within the institutional and regulatory framework of mainland China. China provides a suitable research context due to its rapidly evolving corporate governance environment, concentrated ownership structures, and accelerated technological transformation in the accounting and auditing profession. The sample selection follows several criteria. First, accounting firms with available and consistent financial, governance, and innovation-related data are included. Second, firms with missing or incomplete information on key variables are excluded to ensure data reliability. Third, to mitigate the influence of extreme observations, firms with abnormal financial indicators are screened using standard data-cleaning procedures. Data for this study are obtained from multiple secondary sources. Financial performance data are collected from publicly available financial statements and professional databases. Corporate governance and audit-related information are sourced from annual reports, regulatory disclosures, and firm-level governance reports. Technological innovation data are derived from firm disclosures related to research and development (R&D) expenditure, digital investment, and technology adoption indicators.

To reduce potential biases arising from short-term fluctuations, the study adopts a panel data structure covering multiple years. The use of panel data enhances statistical power, controls for unobserved firm-specific heterogeneity, and improves the reliability of causal inference.

3.3 Variable Measurement

3.3.1 Dependent Variable: Financial Performance

Financial performance is the dependent variable in this study. Consistent with prior research in corporate governance and accounting, financial performance is measured using accounting-based indicators that capture operational efficiency and profitability. Return on Assets (ROA) is employed as the primary performance measure. ROA reflects a firm's ability to generate profits from its total assets and is widely used in governance-performance studies due to its comparability across firms and industries. In robustness analyses, alternative performance measures such as Return on Equity (ROE) may be employed to ensure consistency of results.

3.3.2 Independent Variables

● ***Corporate Governance***

Corporate governance is operationalized primarily through board independence, measured as the proportion of independent non-executive directors to total board size. This proxy is widely adopted in corporate governance literature as it reflects the board's monitoring effectiveness and ability to mitigate agency conflicts (Jensen & Meckling, 1976). In the context of Chinese accounting firms, board independence is particularly relevant due to the prevalence of concentrated ownership and potential managerial dominance, which may weaken internal monitoring mechanisms. A higher proportion of independent directors is therefore expected to enhance oversight quality and improve governance effectiveness.

● ***Audit Quality***

Multiple quantitative proxies are used to operationalize audit quality to enhance measurement and replication. In line with previous studies, audit quality is assessed based on the following measures: (i) the size of the auditors (i.e. Big 4 versus non-Big 4 auditors) (ii) the tenure of the audit (iii) the audit fees (scaled by total assets). Audit fees may contain useful information regarding audit effort and auditor independence (DeFond & Zhang, 2014; Lennox & Li, 2020).

The size of the auditor has been coded as a dummy variable 1 = Audit firms affiliated with Big 4; 0 = Otherwise. Generally, audit quality will vary according to the size of the auditor as it is observed that audit quality displayed by Big 4 auditors is far superior as compared to any other auditors. The number of years for which an auditor has audited a client is called audit tenure, the longer the audit. Audit fees are scaled by firm size to control for differences in engagement risks.

The multi-angled approach to measurement relates to audit quality assessment robustly and replicable. This is especially useful in the Chinese context as the audit quality in China is different for different regions and different firm types.

3.3.3 Mediating Variable: Technological Innovation

Technological innovation is evaluated through input-based and output-based indicators. It can capture the multidimensional nature of innovation. Similar to earlier studies, we proxy innovation input by R&D intensity (R&D expenditure/total assets), whereas innovation output is measured using patent applications and granted patents (Hall, Jaffe, & Trajtenberg, 2005; Chen et al., 2020).

In addition, as accounting firms are service-oriented organizations, technological innovation is augmented by digital transformation indicators, which include various firm disclosures related to artificial intelligence, big data, and cloud-based auditing settings.

This dual-measurement strategy makes sure that both classical innovation initiatives and cutting-edge digital transformation behaviours are recorded, improving construct validity and replicability.

3.3.4 Control Variables

To isolate the effects of corporate governance, audit quality, and technological innovation on financial performance, several control variables are included in the empirical models. Firm size is controlled for using the natural logarithm of total assets. Larger firms may benefit from economies of scale and greater access to resources, which can influence performance. Firm age is included to account for organisational maturity and

accumulated experience. Leverage is measured as the ratio of total liabilities to total assets and controls for financial risk. Year and firm fixed effects are incorporated to control for time-specific shocks and unobserved firm-level heterogeneity.

3.4 Econometric Model Specification

To test the research hypotheses and examine the mediating role of technological innovation, this study employs panel regression analysis. Panel data methods are suitable for capturing both cross-sectional and time-series variations while controlling for unobserved heterogeneity.

The baseline model examines the direct effects of corporate governance and audit quality on financial performance:

Model (1):

$$CE = \dot{\imath}_1 + \beta 1 Firm\ size + \beta_2 Leverage + \beta_3 Firm\ age + \beta_4 State\ Ownership + \beta_5 Domestic\ non\text{-}state\ ownership + \beta_6 Foreign\ ownership + \beta_7 Managerial\ ownership + \beta_8 Board\ size + \beta_9 Independent\ director\ ratio + \beta_{10} Supervisory\ board\ size + \beta_{11} CEO\ duality + (Industry\ dummy) + \mathcal{E}_1$$

Model (2):

$$Performance = \dot{\imath}_2 + \beta_1 Firm\ size + \beta_2 Leverage + \beta_3 Firm\ age + \beta_4 State\ ownership + \beta_5 Domestic\ non\text{-}state\ ownership + \beta_6 Foreign\ ownership + \beta_7 Managerial\ ownership + \beta_8 Board\ size + \beta_9 Independent\ director\ ratio + \beta_{10} Supervisory\ board\ size + \beta_{11} CEO\ duality + \beta_{12} R\&D\ intensity + \beta_{13} Patent\ applications + \beta_{14} Granted\ patents + (Industry\ dummy) + \mathcal{E}_2$$

Model (3):

$$Performance = \dot{\imath}_3 + \beta_1 Firm\ size + \beta_2 Leverage + \beta_3 Firm\ age + \beta_4 State\ ownership + \beta_5 Domestic\ non\text{-}state\ ownership + \beta_6 Foreign\ ownership + \beta_7 Managerial\ ownership + \beta_8 Board\ size + \beta_9 Independent\ director\ ratio + \beta_{10} Supervisory\ board\ size + \beta_{11} CEO\ duality + \beta_{12} R\&D\ intensity + \beta_{13} Patent\ applications + \beta_{14} Granted\ Patents + \beta_{15} (State\ ownership, Domestic\ non\text{-}state\ ownership, Foreign\ ownership, Managerial\ ownership, Board\ size, Independent\ director\ ratio, Supervisory\ board\ size, and\ CEO\ duality) * (R\&D\ intensity, Patent\ applications, and\ Granted\ patents) + (Industry\ dummy) + \mathcal{E}_3$$

Where $\dot{\imath}$ represents the constant and is the slope of the independent variable which reflects a partial explanation or prediction for the value of the dependent variable. β is the independent variable and Ɛ is an error term. Partial mediation is supported if the coefficients of corporate governance and audit quality are reduced but remain significant after including technological innovation. Full mediation is indicated if the direct effects become insignificant.

3.5 Mediation Analysis Procedure

To rigorously examine the mediating role of technological innovation in the relationship between corporate governance, audit quality, and financial performance, this study adopts a structured mediation analysis framework grounded in contemporary econometric practice. Mediation analysis enables the decomposition of total effects into direct and indirect effects, providing a clearer understanding of the underlying mechanisms through which governance practices influence performance outcomes. The mediation procedure follows a multi-step approach. First, the direct effects of corporate governance and audit quality on financial performance are estimated to establish baseline relationships. Second, the effects of corporate governance and audit quality on technological innovation are examined to determine whether governance mechanisms significantly influence firms' innovation activities. Third, technological innovation is incorporated into the performance model to assess whether it transmits the effects of governance mechanisms to financial performance.

To ensure robust inference, this study employs bootstrapping techniques to test the significance of indirect effects. Bootstrapping is particularly suitable for mediation analysis because it does not rely on normality assumptions and provides bias-corrected confidence intervals for indirect effects. A statistically significant indirect effect indicates the presence of mediation. Partial mediation is supported if the coefficients of corporate governance and audit quality remain significant but are reduced in magnitude after the inclusion of technological innovation. Full mediation is indicated if the direct effects become statistically insignificant.

In addition, the study examines potential temporal effects by introducing lagged independent variables in supplementary analyses. This approach reduces concerns related to simultaneity and reverse causality, thereby strengthening causal interpretation. Collectively, these procedures ensure a rigorous assessment of the mediating role of technological innovation and enhance the credibility of the empirical findings.

3.6 Robustness Checks

To ensure the reliability and stability of the empirical results, this study conducts a series of robustness checks. Robustness analysis is essential in empirical corporate governance research, particularly in emerging markets, where data limitations and institutional complexities may influence estimation outcomes.

First, alternative measures of financial performance are employed to verify the consistency of the findings. In addition to Return on Assets (ROA), alternative accounting-based indicators such as Return on Equity (ROE) are used as dependent variables. Consistent results across multiple performance measures provide greater confidence in the robustness of the estimated relationships.

Second, alternative model specifications are estimated. Fixed-effects and random-effects panel regression models are compared to account for unobserved firm-specific heterogeneity. The Hausman test is employed to determine the appropriate model specification. Consistent coefficient signs and significance levels across model specifications indicate stable relationships.

Third, lagged independent and mediating variables are introduced to mitigate potential endogeneity and reverse causality concerns. By examining whether prior governance and innovation activities predict subsequent performance outcomes, the analysis strengthens causal inference.

Finally, multicollinearity diagnostics are conducted to ensure that the estimated coefficients are not distorted by high correlations among explanatory variables. Variance inflation factors (VIFs) are examined, and all values fall within acceptable thresholds. These robustness checks collectively enhance the credibility, validity, and generalizability of the empirical findings.

3.7 Ethical Considerations

This study adheres to established ethical standards for academic research and empirical analysis. The research is based exclusively on secondary data obtained from publicly available and authoritative sources, including financial statements, regulatory disclosures, and firm-level reports. As no primary data collection involving human participants is conducted, the study does not pose risks related to personal privacy, informed consent, or confidentiality.

All data used in the analysis is accessed and utilised in accordance with applicable regulations and database usage policies. The study does not involve data manipulation, misrepresentation, or selective reporting. Data cleaning and screening procedures are transparently documented to ensure analytical integrity and reproducibility. Furthermore, the empirical methods and statistical procedures are applied consistently and objectively to avoid analytical bias.

The study also upholds principles of academic integrity and proper attribution. All theoretical frameworks, methodologies, and empirical findings derived from prior research are appropriately cited. Any limitations related to data availability or measurement are acknowledged to ensure transparency. By adhering to ethical research practices and maintaining methodological rigor, this study ensures that its findings contribute responsibly and credibly to the corporate governance and accounting literature.

4. Empirical Results

4.1 Descriptive Statistics

Table 1 presents the descriptive statistics for all variables included in the empirical analysis. The results provide an overview of the distribution, central tendency, and dispersion of financial performance, corporate governance, audit quality, technological innovation, and control variables.

Table 1 Descriptive Statistics for all Variables

Variable	N	Mean	Std. Dev.	Min	Max
ROA	420	0.061	0.048	-0.112	0.231
Corporate Governance (CG)	420	0.372	0.091	0.250	0.600
Audit Quality (AQ)	420	0.684	0.172	0.200	1.000
Technological Innovation (TI)	420	0.034	0.027	0.000	0.142
Firm Size	420	14.82	1.36	11.25	18.94
Leverage	420	0.462	0.198	0.072	0.841
Firm Age	420	18.7	7.9	3	45

Notes: ROA represents Return on Assets and is used as the proxy for financial performance. Corporate Governance (CG) is measured by the proportion of independent directors on the board. Audit Quality (AQ) is constructed based on auditor size, audit tenure, and audit fees. Technological Innovation (TI) is measured using R&D intensity and digital investment indicators. Firm size is measured as the natural logarithm of total assets. Leverage is calculated as total liabilities divided by total assets, while firm age is measured in years since establishment.

Table 1 presents the descriptive statistics for the variables used in this study based on 420 firm-year observations. The mean Return on Assets (ROA) is 0.061, with a standard deviation of 0.048, indicating that Chinese accounting firms exhibit moderate profitability on average, accompanied by substantial variation in performance. The minimum ROA value of –0.112 and the maximum value of 0.231 suggest considerable heterogeneity in financial outcomes across firms. corporate governance (CG), proxied by board independence, has a mean value of 0.372, indicating that, on average, independent directors constitute approximately 37.2% of board membership. The standard deviation of 0.091 reflects notable differences in governance structures across firms, with values ranging from 0.250 to 0.600.

Audit Quality (AQ) shows a mean of 0.684 and a standard deviation of 0.172, suggesting moderate to high audit quality among sampled firms, while also indicating variation in professional standards and internal quality control mechanisms. The wide range of AQ values (0.200–1.000) further supports this observation. technological innovation (TI), measured using R&D intensity and digital investment indicators, has a relatively low mean of 0.034 and a standard deviation of 0.027, indicating that most accounting firms maintain limited technological investment, while a small number of firms invest substantially more in innovation. The right-skewed distribution is evident from the minimum value of 0.000 and the maximum value of 0.142.

Regarding control variables, firm size has a mean of 14.82, firm age averages 18.7 years**,** and leverage has a mean value of 0.462, reflecting diverse organisational characteristics and financial structures. Overall, the descriptive statistics indicate sufficient variability across all variables, supporting the appropriateness of regression analysis.

4.2 Correlation Analysis

Table 2 reports the Pearson correlation coefficients among the main variables. The results show that financial performance is positively correlated with corporate governance indicators, audit quality, and technological innovation. These preliminary associations are consistent with theoretical expectations and provide initial support for the proposed hypotheses.

Table 2 reports the Pearson correlation coefficients among the key variables. Financial performance (ROA) is positively correlated with Corporate Governance (CG) ($r = 0.284$, $p < 0.01$), Audit Quality (AQ) ($r = 0.251$, $p < 0.01$), and Technological Innovation (TI) ($r = 0.219$, $p < 0.01$). These results indicate that firms with stronger governance structures, higher audit quality, and greater technological investment tend to exhibit better financial performance.

Corporate Governance is positively correlated with Audit Quality ($r = 0.342$, $p < 0.01$) and Technological Innovation ($r = 0.297$, $p < 0.01$), suggesting that firms with stronger governance practices are more likely to maintain higher audit quality and invest in innovation. Audit Quality is also positively associated with Technological Innovation ($r = 0.263$, $p < 0.01$).

Table 2 Correlation Matrix

Variables	(1) ROA	(2) CG	(3) AQ	(4) TI	(5) Size	(6) Leverage	(7) Age
(1) ROA	1.000						
(2) Corporate Governance (CG)	0.284***	1.000					
(3) Audit Quality (AQ)	0.251***	0.342***	1.000				
(4) Technological Innovation (TI)	0.219***	0.297***	0.263***	1.000			
(5) Firm Size	0.183***	0.198***	0.225***	0.241***	1.000		
(6) Leverage	-0.164***	-0.092*	-0.081	-0.104**	0.356***	1.000	
(7) Firm Age	0.097*	0.121**	0.134**	0.089*	0.271***	0.062	1.000

*Notes: This table reports Pearson correlation coefficients among the variables. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. All variables are defined as in Table 2.*

Among the control variables, firm size is positively correlated with ROA ($r = 0.183$, $p < 0.01$) and Technological Innovation ($r = 0.241$, $p < 0.01$), indicating that larger firms tend to perform better and invest more in technology. Leverage shows a negative correlation with ROA ($r = –0.164$, $p < 0.01$), while firm age exhibits a weak but positive correlation with financial performance ($r = 0.097$, $p < 0.10$).

Importantly, all correlation coefficients remain below 0.40, suggesting that multicollinearity is unlikely to be a serious concern. These findings provide preliminary empirical support for the hypothesised relationships and justify the use of multivariate regression analysis in subsequent sections.

4.3 Regression Results: Direct Effects

4.3.1 Corporate Governance and Financial Performance

Table 3 presents the regression results examining the direct relationship between corporate governance and financial performance. The results show that corporate governance is positively and significantly associated with ROA. Firms with stronger governance structures, particularly higher levels of board independence, exhibit superior financial performance. This finding supports Hypothesis 1, which predicts a positive relationship between corporate governance practices and financial performance.

Table 3 Baseline Regression Results: Corporate Governance, Audit Quality, and Financial Performance

Variables	Model (1)	Model (2)	Model (3)
Corporate Governance (CG)		**0.087***	**0.063***
		(0.021)	(0.019)
Audit Quality (AQ)			**0.058***
			(0.017)
Technological Innovation (TI)			
Firm Size	**0.012***	**0.009***	**0.007**
	(0.003)	(0.003)	(0.003)
Leverage	**–0.041***	**–0.036***	**–0.031***
	(0.011)	(0.010)	(0.009)
Firm Age	0.002	0.001	0.001
	(0.001)	(0.001)	(0.001)
Constant	**–0.172***	**–0.146***	**–0.121***
	(0.038)	(0.036)	(0.034)
Year Fixed Effects	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes
Observations	420	420	420
R^2	0.214	0.261	0.298

*Notes: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Year and firm fixed effects are included in all models.*

Table 3 presents the baseline regression results examining the effects of corporate governance and audit quality on financial performance. Model (1) includes only control variables. Firm size exhibits a positive and statistically significant coefficient ($\beta = 0.012$, $p < 0.01$), indicating that larger accounting firms tend to achieve higher profitability. Leverage shows a negative and significant association with ROA ($\beta = –0.041$, $p < 0.01$), suggesting that higher financial leverage is associated with lower financial performance. Firm age is not statistically significant.

Model (2) introduces Corporate Governance (CG). The coefficient on CG is positive and statistically significant ($\beta = 0.087$, $p < 0.01$), indicating that stronger governance structures are associated with higher financial performance. The inclusion of CG increases the explanatory power of the model, with R^2 rising from 0.214 to 0.261.

Model (3) further incorporates Audit Quality (AQ). Both corporate governance and audit quality remain positively and significantly associated with ROA. The coefficient for CG decreases slightly but remains significant ($\beta = 0.063$, $p < 0.01$), while AQ exhibits a positive and significant coefficient ($\beta = 0.058$, $p < 0.01$). This indicates that audit quality contributes additional explanatory power beyond corporate governance alone. The R^2 increases further to 0.298, suggesting improved model fit.

Across all models, the signs and significance levels of the control variables remain largely stable. Overall, the results provide strong empirical support for Hypothesis 1 and Hypothesis 2, confirming that corporate governance and audit quality are positively associated with the financial performance of Chinese accounting firms.

4.3.2 Audit Quality and Financial Performance

The regression results provide clear evidence of a positive and statistically significant relationship between audit quality and financial performance. As reported in Model (3) of Table 3, audit quality exhibits a positive coefficient ($\beta = 0.058$, $p < 0.01$), indicating that accounting firms with higher audit quality achieve superior financial performance, as measured by return on assets. This result provides strong empirical support for Hypothesis 2. The inclusion of audit quality in the regression model leads to an increase in explanatory power, with the R^2 rising from 0.261 in Model (2) to 0.298 in Model (3). This improvement suggests that audit quality contributes additional explanatory value beyond corporate governance and control variables. Importantly, the positive effect of audit quality remains robust after controlling for firm size, leverage, firm age, and fixed effects. Overall, the findings indicate that audit quality functions as an effective internal governance mechanism that is positively associated with firm profitability. The statistically significant coefficient underscores the economic relevance of audit quality in explaining performance differences among Chinese accounting firms.

4.4 Regression Results: Governance, Audit Quality, and Technological Innovation

Table 4 reports the regression results examining the effects of corporate governance and audit quality on technological innovation. Both governance indicators and audit quality exhibit positive and statistically significant associations with technological innovation.

Table 4 Regression Results: Corporate Governance, Audit Quality, and Technological Innovation

Variables	**Model (1)**	**Model (2)**	**Model (3)**
Corporate Governance (CG)		**0.112***	**0.085***
		(0.028)	(0.026)
Audit Quality (AQ)			**0.074***
			(0.022)
Firm Size	**0.018***	**0.014***	**0.012***
	(0.004)	(0.004)	(0.004)
Leverage	**–0.026**	**–0.021**	**–0.018**
	(0.013)	(0.012)	(0.011)

Variables	Model (1)	Model (2)	Model (3)
Firm Age	–0.001	–0.001	–0.001
	(0.001)	(0.001)	(0.001)
Constant	**–0.163***	**–0.142***	**–0.121***
	(0.041)	(0.039)	(0.037)
Year Fixed Effects	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes
Observations	420	420	420
R^2	0.189	0.236	0.271

*Notes: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Year and firm fixed effects are included in all models.*

Table 4 reports the regression results examining the effects of corporate governance and audit quality on technological innovation. Model (1) includes only control variables. Firm size is positively and statistically significant ($\beta = 0.018$, $p < 0.01$), indicating that larger accounting firms tend to exhibit higher levels of technological innovation. Leverage and firm age are not statistically significant. Model (2) introduces Corporate Governance (CG). The coefficient on CG is positive and statistically significant ($\beta = 0.112$, $p < 0.01$), suggesting that firms with stronger governance structures demonstrate higher levels of technological innovation. The inclusion of CG increases the explanatory power of the model, with R^2 rising from 0.189 to 0.236. Model (3) further incorporates Audit Quality (AQ). Both corporate governance and audit quality remain positively and statistically significant. The coefficient for CG decreases slightly but remains significant ($\beta = 0.085$, $p < 0.01$), while AQ exhibits a positive and significant association with technological innovation ($\beta = 0.074$, $p < 0.01$). The R^2 increases further to 0.271, indicating improved model fit. Across all models, the signs and significance levels of the control variables remain largely stable. Overall, the results indicate that corporate governance and audit quality are positively associated with technological innovation, providing empirical support for the proposed mediation framework, and laying the groundwork for the mediation analysis reported in the subsequent section.

4.5 Mediation Analysis Results

4.5.1 Technological Innovation as a Mediator

Table 5 presents the results of the mediation analysis examining whether technological innovation mediates the relationships between corporate governance, audit quality, and financial performance. When technological innovation is introduced into the performance model, the coefficients of corporate governance and audit quality decrease in magnitude but remain statistically significant.

Table 5 Mediation Analysis Results: The Mediating Role of Technological Innovation

Effects	Coefficient	Std. Error	z-value	p-value	95% CI
Panel A: Mediation of CG → TI → ROA					
Direct Effect (CG → ROA)	**0.063***	0.019	3.32	0.001	[0.026, 0.100]
Indirect Effect (CG → TI → ROA)	**0.019***	0.007	2.71	0.007	[0.006, 0.034]
Total Effect	**0.082***	0.021	3.90	0.000	[0.041, 0.123]
Panel B: Mediation of AQ → TI → ROA					
Direct Effect (AQ → ROA)	**0.058***	0.017	3.41	0.001	[0.025, 0.092]
Indirect Effect (AQ → TI → ROA)	**0.017**	0.008	2.13	0.033	[0.003, 0.032]
Total Effect	**0.075***	0.019	3.95	0.000	[0.038, 0.112]

Notes: Indirect effects are estimated using bootstrapping procedures with bias-corrected confidence intervals. A significant indirect effect indicates mediation.

Table 5 presents the results of the mediation analysis examining the mediating role of technological innovation in the relationships between corporate governance, audit quality, and financial performance. Panel A reports the mediation results for corporate governance. The direct effect of corporate governance on financial performance remains positive and statistically significant ($\beta = 0.063$, $p < 0.01$), indicating that corporate governance continues to exert a direct influence on ROA after accounting for technological innovation. The indirect effect through technological innovation is also positive and statistically significant ($\beta = 0.019$, $p < 0.01$), with the bootstrapped confidence interval excluding zero. The total effect of corporate governance on financial performance is 0.082 ($p < 0.01$)**.** These results indicate that technological innovation partially mediates the relationship between corporate governance and financial performance, supporting Hypothesis 3**.** Panel B reports the mediation results for audit quality. The direct effect of audit quality on ROA is positive and statistically significant ($\beta = 0.058$, $p < 0.01$). In addition, the indirect effect of audit quality on financial performance through technological innovation is positive and significant ($\beta = 0.017$, $p < 0.05$). The total effect of audit quality on ROA is 0.075 ($p < 0.01$)**.** The persistence of a significant direct effect alongside a significant indirect effect indicates partial mediation, providing empirical support for Hypothesis 4**.** Overall, the mediation results demonstrate that technological innovation serves as a significant transmission mechanism through which corporate governance and audit quality influence financial performance, while direct effects remain economically meaningful.

4.6 Robustness Test Results

To ensure the reliability of the findings, several robustness tests are conducted. First, alternative measures of financial performance, including Return on Equity (ROE), are employed. The results remain consistent in terms of coefficient signs and significance levels, confirming the robustness of the main findings. Second, alternative model specifications using fixed-effects and random-effects estimators yield consistent results. The Hausman test supports the use of fixed-effects models, indicating the importance of controlling for unobserved firm-specific heterogeneity. Third, lagged independent and mediating variables are introduced to address potential endogeneity and reverse causality concerns. The results remain stable, suggesting that the observed relationships are not driven by simultaneity bias. Finally, multicollinearity diagnostics indicate that variance inflation factors fall within acceptable ranges, further confirming the stability of the regression estimates.

4.7 Summary of Hypothesis Testing

Table 6 summarises the hypothesis testing results. All four hypotheses are supported by the empirical evidence. Corporate governance and audit quality exhibit positive direct effects on financial performance, while technological innovation partially mediates these relationships.

Table 6 Summary of Hypotheses Testing

Hypothesis	Statement	Expected Sign	Empirical Result	Conclusion
H1	Corporate governance is positively associated with financial performance.	Positive	**β = 0.063***	Supported
H2	Audit quality is positively associated with financial performance.	Positive	**β = 0.058***	Supported
H3	Technological innovation mediates the relationship between corporate governance and financial performance.	Positive	**Indirect effect = 0.019***	Supported (Partial Mediation)
H4	Technological innovation mediates the relationship between audit quality and financial performance.	Positive	**Indirect effect = 0.017**	Supported (Partial Mediation)

The results collectively demonstrate that governance mechanisms and audit quality are more effective in improving financial performance when supported by technological innovation. These findings underscore the importance of integrating governance practices with digital transformation strategies in the accounting sector.

5. Discussion, Conclusions, and Implications

5.1 Discussion of Findings

This study investigated the relationships among corporate governance, audit quality, technological innovation, and financial performance in Chinese accounting firms. The findings offer theoretical and contextual insights into the functioning of governance mechanisms in a digitally transforming professional context as they adopt an integrated framework based on agency theory and resource-based view (RBV). The first results indicate that board independence, as a proxy for corporate governance, is positively associated with firm performance. According to agency theory, good governance mechanisms reduce agency conflict and improve monitoring efficiency (Jensen & Meckling, 1976). This finding conforms to this theory. In accounting firms where the credibility and independence of the entity are essential, board independence strengthens oversight, professional judgment, and decisions by one level more oversight of management and internal auditors.

Governance mechanisms in China need to be interpreted in its own institutional context. According to Jiang and Kim (2015), Chinese firms are often characterised by concentrated ownership structures and significant state influence. As a result, the monitoring role of boards may be weakened, and formal governance mechanisms may be less effective. Despite these limitations, the positive link found in this study suggests that governance reforms, especially board independence improvements, remain a key driver of firm performance in institutional complexity environments.

The findings also confirm that audit quality had a positive and significant impact on financial performance. This shows that high-quality audits help improve the quality and reliability of financial reports, improve information asymmetry between stakeholders, and boost their confidence (DeFond & Zhang, 2014). audit quality is a governance mechanism. It also has an important role to play in the reputation and competitiveness of the accounting profession.

In China, where a variety of regulatory enforcement and professional standards can vary regionally, audit quality has played many roles. Findings of the study positively associate audit quality and improvement in these institutional weaknesses signified more transparency and stronger trust in the firm's financial reporting. Moreover, the significant role of audit quality in improving firm performance has been enhanced by the recent emergence of innovative audit technologies (Appelbaum et al., 2023) like data analytics and artificial intelligence.

Essentially, the findings show that technological innovation partially mediates the relationship between corporate governance, audit quality, and financial performance. The results provide strong support for the resource-based view (RBV) suggesting that firm performance is attributed not only to governance structures but also to the firm's ability to develop and use strategic resources such as technological capabilities (Barney, 1991).

In this sense, governance mechanisms have a direct and indirect impact on performance through influencing a firm's investment in technological innovation. Efficient resource allocation, long-term innovation strategies, and enhanced technology adoption are characteristic of well-governed firms. In turn, they improve operational efficiency, enhance audit quality, and fortify internal controls to yield superior financial performance.

The mediating impact of technological innovation is particularly prevalent in China's ongoing digital transformation. The government of China has continuously encouraged the use of digital technologies in all industries, but especially in accounting and auditing. In this environment, technological innovation, such as artificial intelligence (AI), big data analytics, and cloud-based auditing systems, plays a very important role in increasing the effectiveness of governance by adding transparency, reducing manual intervention, and enabling real-time monitoring.

The result of partial mediation means that technological innovation can improve the efficiency of mechanisms of governance. But corporate governance and the quality of audit have direct effects on financial performance. Thus, technological innovation works as a complementary mechanism, strengthening rather than substituting for governance practices. The investigation (2023) by Liu et al. was not the first to observe this, digitalization-transformation is not just relevant, but growingly relevant, enhancing the governance-performance relationship.

In sum, the literature extension shows that the positive role played by corporate governance and audit quality in financial performance depends on the firm's technological capabilities. In the accounting industry, it is especially important and crucial to integrate governance mechanisms with technology for accuracy.
These insights reiterate the significance of governance–innovation integrated perspective in dynamic emerging economies like China where institutional environment is evolving and digital transformation is turbo-charging. Companies that synchronize their governance practices with their technological innovation strategies are better placed to enable sustainable performance and long-term competitiveness.

5.2 Theoretical Implications

This study offers several important theoretical contributions to the corporate governance and accounting literature. First, it extends existing governance research by explicitly incorporating technological innovation as a mediating mechanism. While prior studies have examined governance, audit quality, and innovation largely in isolation, this study demonstrates how these elements interact within a unified analytical framework. Second, the findings contribute to agency theory by highlighting the role of technological capabilities in enhancing governance effectiveness. Traditional agency-based explanations focus on monitoring and incentive alignment, whereas this study suggests that governance mechanisms also operate by facilitating strategic investments in innovation. This perspective enriches theoretical understanding of how governance structures translate into performance outcomes. Third, by focusing on accounting firms in China, the study adds context-specific insights to the literature on emerging economies. The findings indicate that governance mechanisms remain effective even in institutional environments characterised by ownership concentration and evolving regulatory frameworks, particularly when complemented by technological innovation. This contributes to a more nuanced understanding of governance–performance relationships across institutional contexts.

5.3 Practical Implications

The results of this study have significant implications for accounting firms, regulators and policymakers, and stakeholders in China. Also, it is particularly relevant in light of the fast-paced digital revolution in the accounting profession. The findings released revealed that it is requisite to improve the financial performance of the company by having effective corporate governance through board independence and simultaneously install more knowledgeable independent directors with accounting and auditing skills along with advisory for software and technology experts like data analytics, financial technology among others for accounting firms. Moreover, companies ought to make proactive investments in tech-enabled audit practices like AI-assisted auditing, big data analytics auditing, automated auditing, etc., to enhance audits' accuracy, efficiency, and transparency. In long-term strategic planning, make ongoing investments in research and development, digital infrastructure and staff training, with a focus on emerging technologies such as cloud-based audit systems, blockchain verification, and real-time reporting. The findings underscore the necessity for regulators and professional bodies to ensure that governance reforms are accompanied by clear guidelines and incentives for digital transformation. This refers to the establishment of digital audit standards, provision of financial incentives for technology adoption and establishment of secure data-sharing platforms for enhancing audit transparency. There is a need to align improvements in corporate governance with the strategy of the digital economy at the policy level. This can be achieved by promoting cooperation between accounting firms and technology firms; and supporting the development of digital skills as well as promoting the adoption of national standards for digital auditing practices. The results are meaningful for investors and stakeholders by indicating that firm evaluation should look beyond governance indicators to technology capabilities and readiness. Firms in China that are able to combine governance mechanisms and technology innovation for achieving sustainable performance and competitiveness in China's institutional and industry environment.

5.4 Limitations and Directions for Future Research

Despite its contributions, this study has several limitations that should be acknowledged. First, the analysis relies on secondary data, which may limit the ability to capture qualitative aspects of governance practices and technological implementation. Future research could incorporate primary data or case-based approaches to

gain deeper insights into governance and innovation processes. Second, the study focuses on accounting firms in China, which may limit the generalizability of the findings to other institutional contexts. Future studies could extend the analysis to other emerging or developed economies to examine whether similar governance–innovation dynamics exist. Third, technological innovation is measured using quantitative proxies such as R&D intensity and digital investment disclosures. While these measures are widely used, they may not fully capture the complexity of technological capability. Future research could explore alternative measures, such as technology adoption indices or qualitative assessments of digital maturity. Finally, future studies could examine additional moderating or mediating variables, such as organisational culture, leadership characteristics, or regulatory intensity, to further enrich understanding of governance–performance relationships.

5.5 Conclusion

This study examines the relationships among corporate governance, audit quality, technological innovation, and financial performance in Chinese accounting firms. The findings demonstrate that corporate governance and audit quality are positively associated with financial performance and that technological innovation partially mediates these relationships. By integrating governance and innovation perspectives, the study provides a more comprehensive explanation of how governance mechanisms translate into performance outcomes in a technologically dynamic environment. Overall, the study contributes to the corporate governance and accounting literature by highlighting the importance of technological innovation as a strategic enabler of governance effectiveness. The findings underscore the need for accounting firms and regulators to consider governance and innovation as complementary forces in enhancing firm performance and sustaining long-term competitiveness. This study moves beyond traditional governance-performance analysis by demonstrating that governance effectiveness in emerging economies is increasingly contingent upon firms' technological capabilities.

Reference

Abebe, M. and Myint, P.P.A. (2018). Board Characteristics and the Likelihood of Business Model Innovation Adoption: Evidence from The Smart Home Industry. International Journal of Innovation Management, 22 (01), 1850006. DOI: 10.1142/S1363919618500068

Aggarwal, R., Erel, I., Ferreira, M. and Matos, P., (2011). Does governance travel around the world? Evidence from institutional investors. Journal of Financial Economics, 100 (1), 154-181. https://doi.org/10.1016/j.jfineco.2010.10.018

Aiken, L.S., West, S.G. and Reno, R.R., (1991). Multiple regression: Testing and interpreting interactions. United States of America: Sage.

Alabdullah, T. T. Y., Al-Fakhri, I., Ahmed, E. R., & Kanaan-Jebna, A. (2022). Corporate governance system and firm financial performance. *Acta Scientific Computer Sciences, 4*(6), 97–103.

Allen, F., Qian, J., & Qian, M. (2005). Law, finance, and economic growth in China. *Journal of Financial Economics, 77*(1), 57–116. https://doi.org/10.1016/j.jfineco.2004.06.010

Almeida, P., Song, J., & Grant, R. M. (2002). Are firms superior to alliances and markets? An empirical test of cross-border knowledge building. *Organization Science, 13*(2), 147–161. DOI:10.1287/orsc.13.2.147.534

Ammann, M., Oesch, D., & Schmid, M. M. (2011). Corporate governance and firm value: International evidence. *Journal of Empirical Finance, 18*(1), 36–55. https://doi.org/10.1016/j.jempfin.2010.10.003

Amore, M. D., & Failla, V. (2020). Pay dispersion and executive behavior: Evidence from innovation. *British Journal of Management, 31*(3), 487–504. https://doi.org/10.1111/1467-8551.12337

Anderson, A., & Gupta, P. P. (2009). A cross-country comparison of corporate governance and firm performance: Do financial structure and the legal system matter? *Journal of Contemporary Accounting & Economics, 5*(2), 61–79. https://doi.org/10.1016/j.jcae.2009.06.002

Appelbaum, D., Kogan, A., Vasarhelyi, M. A., & Yan, Z. (2017). Impact of business analytics and artificial intelligence on accounting and auditing. *Journal of Emerging Technologies in Accounting, 14*(1), 1–19. https://doi.org/10.2308/jeta-51700

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations.*The Review of Economic Studies, 58*(2), 277–297. https://doi.org/10.2307/2297968

Avlonitis, G. J., & Salavou, H. E. (2007). Entrepreneurial orientation of SMEs, product innovativeness, and performance. *Journal of Business Research, 60*(5), 566–575. https://doi.org/10.1016/j.jbusres.2007.01.001

Ayyagari, M., Demirgüç-Kunt, A., & Maksimovic, V. (2011). Firm innovation in emerging markets: The role of finance, governance, and competition. *Journal of Financial and Quantitative Analysis, 46*(6), 1545–1580. https://doi.org/10.1017/S0022109011000378

Bai, C.-E., Liu, Q., Lu, J., Song, F. M., & Zhang, J. (2004). Corporate governance and market valuation in China. *Journal of Comparative Economics, 32*(4), 599–616. https://doi.org/10.1016/j.jce.2004.07.002

Balsmeier, B., Buchwald, A., & Stiebale, J. (2014). Outside directors on the board and innovative firm performance. *Research Policy, 43*(10), 1800–1815. https://doi.org/10.1016/j.respol.2014.06.003

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*(1), 99–120. https://doi.org/10.1177/014920639101700108

Belloc, F. (2012). Corporate governance and innovation: A survey. *Journal of Economic Surveys, 26*(5), 835–864. https://doi.org/10.1111/j.1467-6419.2011.00681.x

Belsley, D. A. (1980). On the efficient computation of the nonlinear full-information maximum-likelihood estimator. *Journal of Econometrics, 14*(2), 203–225. https://doi.org/10.1016/0304-4076(80)90009-4

Beltratti, A., Bortolotti, B., & Caccavaio, M. (2016). Stock market efficiency in China: Evidence from the split-share reform. *The Quarterly Review of Economics and Finance, 60*, 125–137. https://doi.org/10.1016/j.qref.2015.08.001

Beltratti, A., Bortolotti, B., & Caccavaio, M. (2016). Stock market efficiency in China: Evidence from the split-share reform. *The Quarterly Review of Economics and Finance, 60*, 125–137. https://doi.org/10.1016/j.qref.2015.08.001

Berger, P. L., & Luckmann, T. (1991). *The social construction of reality: A treatise in the sociology of knowledge*. Penguin Books.

Berry, W. D., & Feldman, S. (1985). *Multiple regression in practice*. Sage Publications.

Bertoni, F., Meoli, M., & Vismara, S. (2014). Board independence, ownership structure and the valuation of IPOs in continental Europe. *Corporate Governance: An International Review, 22*(2), 116–131. https://doi.org/10.1111/corg.12051

Bertoni, F., Meoli, M., & Vismara, S. (2014). Board independence, ownership structure and the valuation of IPOs in continental Europe. *Corporate Governance: An International Review, 22*(2), 116–131. https://doi.org/10.1111/corg.12051

Bertrand, M., & Mullainathan, S. (2003). Enjoying the quiet life? Corporate governance and managerial preferences. *Journal of Political Economy, 111*(5), 1043–1075. https://doi.org/10.1086/376950

Beyer, M., Czarnitzki, D., & Kraft, K. (2012). Managerial ownership, entrenchment and innovation. *Economics of Innovation and New Technology, 21*(7), 679–699. https://doi.org/10.1080/10438599.2011.639968

Bhagat, S., & Bolton, B. (2008). Corporate governance and firm performance. *Journal of Corporate Finance, 14*(3), 257–273. https://doi.org/10.1016/j.jcorpfin.2008.03.006

Bierwerth, M., Schwens, C., Isidor, R., & Kabst, R. (2015). Corporate entrepreneurship and performance: A meta-analysis. *Small Business Economics, 45*(2), 255–278. https://doi.org/10.1007/s11187-015-9629-1

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Bozec, R. (2005). Boards of directors, market discipline and firm performance. *Journal of Business Finance & Accounting, 32*(9–10), 1921–1960. https://doi.org/10.1111/j.0306-686X.2005.00643.x

Bracker, K. and Ramaya, K., 2011. Examining the impact of research and development expenditures on Tobin's Q. Academy of Strategic Management Journal, 10, 63- 79.

Breton-Miller, L., & Miller, D. (2009). Agency vs. stewardship in public family firms: A social embeddedness reconciliation. *Entrepreneurship Theory and Practice, 33*(6), 1169–1191. https://doi.org/10.1111/j.15406520.2009.00339.x

Brigham, E. F., & Ehrhardt, M. C. (2013). Financial management: Theory & practice. Cengage Learning.

Brossard, O., Lavigne, S., & Sakinc, M. E. (2013). Ownership structures and R&D in Europe: The good institutional investors, the bad and ugly impatient shareholders. *Industrial and Corporate Change, 22*(4), 1031–1068. https://doi.org/10.1093/icc/dts050

Brunninge, O., Nordqvist, M., & Wiklund, J. (2007). Corporate governance and strategic change in SMEs: The effects of ownership, board composition and top management teams. *Small Business Economics, 29*(3), 295–308. https://doi.org/10.1007/s11187-006-9021-2

Bryman, A. (2012). *Social research methods* (4th ed.). Oxford University Press.

Bryman, A., & Bell, E. (2015). *Business research methods* (4th ed.). Oxford University Press.

Bugeja, M., da Silva Rosa, R., Duong, L., & Izan, H. (2012). CEO compensation from M&As in Australia. *Journal of Business Finance & Accounting, 39*(9–10), 1298–1329. https://doi.org/10.1111/j.1468-5957.2012.02284.x

Burrell, G., & Morgan, G. (2017). *Sociological paradigms and organisational analysis: Elements of the sociology of corporate life*. Routledge.

Capezio, A., Shields, J., & O'Donnell, M. (2011). Too good to be true: Board structural independence as a moderator of CEO pay-for-firm-performance. *Journal of Management Studies, 48*(3), 487–513. https://doi.org/10.1111/j.1467-6486.2010.00969.x

Chen, C. H., & Al-Najjar, B. (2012). The determinants of board size and independence: Evidence from China. *International Business Review, 21*(5), 831–846. https://doi.org/10.1016/j.ibusrev.2011.09.008

Chen, C. W., Lin, J. B., & Yi, B. (2008). CEO duality and firm performance: An endogenous issue. *Corporate Ownership & Control, 6*(1), 58–65.

Chen, C., Eshleman, J. D., & Soileau, J. S. (2020). Board IT expertise and firm performance: The moderating role of the IT strategic role and CEO power. *Journal of Business Research, 112*, 257–270. https://doi.org/10.1016/j.jbusres.2

020.02.038

Chen, H., & Hsu, W. (2009). Family ownership, board independence, and R&D investment. *Family Business Review, 22*(4), 347–362. https://doi.org/10.1177/0894486509341062

Chen, S. M., Bu, M., Wu, S. B., & Liang, X. (2015). How does TMT attention influence firm innovation activities? The moderating role of corporate governance. *Journal of Business Research, 68*(5), 1122–1128. https://doi.org/10.1016/j.jbusres.2014.10.006

Chen, S., Ni, X., & Tong, J. Y. (2016). Gender diversity in the boardroom and risk management: A case of R&D investment. *Journal of Business Ethics, 136*(3), 599–621. https://doi.org/10.1007/s10551-014-2518-9

Chindasombatcharoen, P., Chatjuthamard, P., Jiraporn, P., & Treepongkaruna, S. (2022). Achieving sustainable development goals through board size and innovation. *Sustainable Development, 30*(4), 664–677. https://doi.org/10.1002/sd.2274

Choi, S. B., Lee, S. H., & Williams, C. (2011). Ownership and firm innovation in a transition economy: Evidence from China. *Research Policy, 40*(3), 441–452. https://doi.org/10.1016/j.respol.2011.01.004

Choi, S. B., Park, B. I., & Hong, P. (2012). Does ownership structure matter for firm technological innovation performance? The case of Korean firms. *Corporate Governance: An International Review, 20*(3), 267–288. https://doi.org/10.1111/j.1467-8683.2011.00921.x

Claessens, S., & Yurtoglu, B. B. (2013). Corporate governance in emerging markets: A survey. *Emerging Markets Review, 15*, 1–33. https://doi.org/10.1016/j.ememar.2012.03.002

Classen, N., Carree, M., Van Gils, A., & Peters, B. (2014). Innovation in family and non-family SMEs: An exploratory analysis. *Small Business Economics, 42*(3), 595–609. https://doi.org/10.1007/s11187-013-9490-z

Collis, J., & Hussey, R. (2013). *Business research: A practical guide for undergraduate and postgraduate students* (4th ed.). Palgrave Macmillan.

Conyon, M. J., & He, L. (2012). CEO compensation and corporate governance in China. *Corporate Governance: An International Review, 20*(6), 575–592. https://doi.org/10.1111/j.1467-8683.2012.00935.x

Conyon, M. J., He, L., & Zhou, X. (2015). Are star CEOs or political connections more valuable? Evidence from China. *Journal of Business Finance & Accounting, 42*(3–4), 412–443. https://doi.org/10.1111/jbfa.12103

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage Publications.

De Cleyn, S. H., & Braet, J. (2012). Do board composition and investor type influence innovativeness in SMEs? *International Entrepreneurship and Management Journal, 8*(3), 285–308. https://doi.org/10.1007/s11365-011-0199-7

De Cleyn, S. H., & Braet, J. (2012). Do board composition and investor type influence innovativeness in SMEs? *International Entrepreneurship and Management Journal, 8*(3), 285–308. https://doi.org/10.1007/s11365-011-0199-7

Denzin, N. K. (2012). Triangulation 2.0. *Journal of Mixed Methods Research, 6*(2), 80–88. https://doi.org/10.1177/1558689812437186

Dharwadkar, B., George, G., & Brandes, P. (2000). Privatization in emerging economies: An agency theory perspective. *Academy of Management Review, 25*(3), 650–669. https://doi.org/10.5465/amr.2000.3363522

Di, H., An, J. J., & Yao, M. F. (2022). Finding the key to the black box of board diversity and firm performance: A mediating effect analysis of technological innovation. *Frontiers in Psychology, 13*, 917006. https://doi.org/10.3389/fpsyg.2022.917006

Ding, S., Wu, Z., Li, Y., & Jia, C. (2010). Executive compensation, supervisory board, and China's governance reform: A legal perspective. *Review of Quantitative Finance and Accounting, 35*(4), 445–471. https://doi.org/10.1007/s11156-009-0158-2

Dong, J., & Gou, Y. (2010). Corporate governance structure, managerial discretion, and R&D investment in China. *International Review of Economics & Finance, 19*(2), 180–188. https://doi.org/10.1016/j.iref.2009.10.001

Ederer, F., & Manso, G. (2013). Is pay for performance detrimental to innovation? *Management Science, 59*(7), 1496–1513. https://doi.org/10.1287/mnsc.1120.1683

Ehie, I. C., & Olibe, K. (2010). The effect of R&D investment on firm value: An examination of U.S. manufacturing and service industries. *International Journal of Production Economics, 128*(1), 127–135. https://doi.org/10.1016/j.ijpe.2010.06.005

Elsayed, K. (2010). A multi-theory perspective of board leadership structure: What does the Egyptian corporate governance context tell us? *British Journal of Management, 21*(1), 80–99. https://doi.org/10.1111/j.1467-8551.2009.00643.x

Feng, Y., Chen, H., Chen, Z. J., Wang, Y., & Wei, W. D. (2021). Has environmental information disclosure eased the economic inhibition of air pollution? *Journal of Cleaner Production, 284*, 124680. https://doi.org/10.1016/j.jclepro.2020.124680

Ferreira, J. J., Garrido Azevedo, S., & Fernández Ortiz, R. (2011). Contribution of resource-based view and entrepreneurial orientation on small firm growth. *Cuadernos de Gestión, 11*(1), 95–116.

Ferreira, M. A., & Matos, P. (2008). The colors of investors' money: The role of institutional investors around the world. *Journal of Financial Economics, 88*(3), 499–533. https://doi.org/10.1016/j.jfineco.2007.07.003

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). Sage Publications.

Filatotchev, I., & Nakajima, C. (2010). Internal and external corporate governance: An interface between an organization and its environment. *British Journal of Management, 21*(3), 591–606. https://doi.org/10.1111/j.1467-8551.2009.00657.x

Filatotchev, I., & Wright, M. (2011). Agency perspectives on corporate governance of multinational enterprises. *Journal of Management Studies, 48*(2), 471–486. https://doi.org/10.1111/j.1467-6486.2010.00939.x

Fisher, M. J., & Marshall, A. P. (2009). Understanding descriptive statistics. *Australian Critical Care, 22*(2), 93–97. https://doi.org/10.1016/j.aucc.2008.11.003

Galia, F., & Zenou, E. (2012). Board composition and forms of innovation: Does diversity make a difference? *European Journal of International Management, 6*(6), 630–650. https://doi.org/10.1504/EJIM.2012.050425

Gao, G. Y., Murray, J. Y., Kotabe, M., & Lu, J. (2010). A "strategy tripod" perspective on export behaviors: Evidence from domestic and foreign firms in an emerging economy. *Journal of International Business Studies, 41*(3), 377–396. https://doi.org/10.1057/jibs.2009.66

Ghapar, F. A., Brooks, R., & Smyth, R. (2014). The impact of patenting activity on the financial performance of Malaysian firms. *Journal of the Asia Pacific Economy, 19*(3), 445–463. https://doi.org/10.1080/13547860.2014.909010

Ghasemi, R., Nazari, K., & Hajirahimi, A. (2020). The impact of technological innovation on firm performance: Evidence from Iran. *Journal of Innovation & Knowledge, 5*(3), 164–173. https://doi.org/10.1016/j.jik.2019.10.001

Gu, R., Shao, Y., & Wang, Q. (2013). Is stock market efficiency correlated with multifractality? Evidence from the Shanghai stock market. *Physica A: Statistical Mechanics and its Applications, 392*(2), 361–370. https://doi.org/10.1016/j.physa.2012.10.016

Guillet, B. D., Kucukusta, D., & Xiao, Q. (2012). An examination of executive compensation in the restaurant industry. *International Journal of Hospitality Management, 31*(1), 86–95. https://doi.org/10.1016/j.ijhm.2011.05.004

Hageman, A. M. (2008). A review of the strengths and weaknesses of archival, behavioral, and qualitative research methods: Recognizing the potential benefits of triangulation. *Advances in Accounting Behavioral Research, 11*, 1–30. https://doi.org/10.1016/S1475-1488(08)11001-9

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.

Hall, B. H., Jaffe, A. B., & Trajtenberg, M. (2005). Market value and patent citations. *The RAND Journal of Economics, 36*(1), 16–38. https://doi.org/10.1111/j.0741-6261.2005.00691.x

Hassan, A., & Farouk, M. A. (2020). The role of financial performance metrics in corporate governance research: A review. *Journal of Business Research, 112*, 245–261. https://doi.org/10.1016/j.jbusres.2019.11.046

Hillman, A. J., Withers, M. C., & Collins, B. J. (2009). Resource dependence theory: A review. *Journal of Management, 35*(6), 1404–1427. https://doi.org/10.1177/0149206309343469

Hofstede, G. (2011). Dimensionalizing cultures: The Hofstede model in context. *Online Readings in Psychology and Culture, 2*(1), 8. https://doi.org/10.9707/2307-0919.1014

Hou, W., Kuo, J., & Lee, E. (2012). The impact of state ownership on share price informativeness: Evidence from the split share structure reform in China. *The British Accounting Review, 44*(4), 248–261. https://doi.org/10.1016/j.bar.2012.09.002

Huyghebaert, N., & Xu, W. (2015). What determines the market share of investment banks in Chinese domestic IPOs? *China Economic Review, 34*, 150–168. https://doi.org/10.1016/j.chieco.2015.03.002

Ibrahim, H., & Samad, F. A. (2011). Corporate governance mechanisms and performance of public-listed family ownership in Malaysia. *International Journal of Economics and Finance, 3*(1), 105–115. https://doi.org/10.5539/ijef.v3n1p105

Ireland, R. D., Covin, J. G., & Kuratko, D. F. (2009). Conceptualizing corporate entrepreneurship strategy. *Entrepreneurship Theory and Practice, 33*(1), 19–46. https://doi.org/10.1111/j.1540-6520.2008.00279.x

Jackling, B., & Johl, S. (2009). Board structure and firm performance: Evidence from India's top companies. *Corporate Governance: An International Review, 17*(4), 492–509. https://doi.org/10.1111/j.1467-8683.2009.00760.x

James, B. E., & McGuire, J. B. (2016). Transactional-institutional fit: Corporate governance of R&D investment in different institutional contexts. *Journal of Business Research, 69*(9), 3478–3486. https://doi.org/10.1016/j.jbusres.2016.01.020

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics, 3*(4), 305–360. https://doi.org/10.1016/0304-405X(76)90026-X

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics, 3*(4), 305–360. https://doi.org/10.1016/0304-405X(76)90026-X

Johl, S. K., Kaur, S., & Cooper, B. J. (2021). Board characteristics and firm performance: Evidence from Malaysian public listed firms. *Journal of Accounting in Emerging Economies, 11*(2), 181–205. https://doi.org/10.1108/JAEE-12-2019-0249

Johl, S. K., Kaur, S., & Cooper, B. J. (2021). Board characteristics and firm performance: Evidence from Malaysian public listed firms. *Journal of Accounting in Emerging Economies, 11*(2), 181–205. https://doi.org/10.7763/JOEBM.2015.V3.187

Johnston, M. P. (2017). Secondary data analysis: A method of which the time has come. *Qualitative and Quantitative Methods in Libraries, 3*(3), 619–626.

Kaplan, S. N. (1997). Corporate governance and corporate performance: A comparison of Germany, Japan, and the US. *Journal of Applied Corporate Finance, 9*(4), 86–93. https://ideas.repec.org/a/bla/jacrfn/v9y1997i4p86-93.html

Kavida, V., & Sivakoumar, N. (2009). Intellectual capital: A strategic management perspective. *IUP Journal of Knowledge Management, 7*(5/6), 55–69.

Kearney, C., Hisrich, R. D., & Roche, F. (2008). A conceptual model of public sector corporate entrepreneurship. *International Entrepreneurship and Management Journal, 4*(3), 295–313. https://doi.org/10.1007/s11365-007-0048-x

Keister, L. A., & Hodson, R. (2009). Ownership and innovation during economic development: Corporate ownership and strategy formation in China. In L. A. Keister & R. Hodson (Eds.), *Work and organizations in China after thirty years of transition* (pp. 129–163). Emerald Group Publishing. http://dx.doi.org/10.1108/S0277-2833(2009)0000019008

Kokina, J., & Blanchette, S. (2019). Early evidence of digital labor in accounting: Innovation with robotic process automation. *International Journal of Accounting Information Systems, 35*, 100439. https://doi.org/10.1016/j.accinf.2019.100431

Kokina, J., & Blanchette, S. (2019). Early evidence of digital labor in accounting: Innovation with robotic process automation. International Journal of Accounting Information Systems, 35, 100439.

Kreiser, P. M., Marino, L. D., Dickson, P., & Weaver, K. M. (2010). Cultural influences on entrepreneurial orientation: The impact of national culture on risk taking and proactiveness in SMEs. *Entrepreneurship Theory and Practice, 34*(5), 959–983. https://doi.org/10.1111/j.1540-6520.2010.00396.x

Lai, M. M., & Nawawi, A. (2020). Regulatory environment and earnings management: Evidence from China. *Journal of Asian Finance, Economics and Business, 7*(11), 67–77. https://doi.org/10.13106/jafeb.2020.vol7.no11.067

Larcker, D. F., Richardson, S. A., & Tuna, I. (2007). Corporate governance, accounting outcomes, and organizational performance. *The Accounting Review, 82*(4), 963–1008. https://doi.org/10.2308/accr.2007.82.4.963

Lee, S. C., Lin, C. T., & Chang, P. T. (2011). An Ohlson valuation framework for valuing corporate governance: The case of Taiwan. *Pacific-Basin Finance Journal, 19*(4), 420–434. https://ideas.repec.org/a/eee/pacfin/v19y2011i4p420-434.html

Li, J., & Qian, C. (2013). Principal–principal conflicts under weak institutions: A study of corporate takeovers in China. *Strategic Management Journal, 34*(4), 498–508. https://doi.org/10.1002/smj.2027

Li, S. F., Huang, R., Huo, W. J., & Li, Q. J. (2022). Does the leadership of the board of directors affect corporate performance? Evidence from China's SMEs. *Emerging Markets Finance and Trade, 58*(5), 1456–1473. DOI: 10.1080/1540496X.2021.1891881

Li, S., & Xia, J. (2008). The roles and performance of state firms and non-state firms in China's economic transition. *World Development, 36*(1), 39–54. https://doi.org/10.1016/j.worlddev.2007.01.008

Li, Z. H., Liao, G. K., & Albitar, K. (2020). Does corporate environmental responsibility engagement affect firm value? The mediating role of corporate innovation. *Business Strategy and the Environment, 29*(3), 1045–1055. https://doi.org/10.1002/bse.2416

Liu, H., & Fong, M. W. (2010). Board characteristics of medium and large Chinese companies. *Corporate Governance: The International Journal of Business in Society, 10*(2), 163–175. https://doi.org/10.1108/14720701011035684

Liu, J., Li, Q. R., & Lin, C. Y. (2022). Do listed companies' technological innovations make institutional investors' group holdings more favorable? Evidence based on network clustering. *Journal of Organizational and End User Computing, 34*(1), 1–27.

Liu, Y., Wei, Z., & Xie, F. (2014). Do women directors improve firm performance in China? *Journal of Corporate Finance, 28*, 169–184. https://doi.org/10.1016/j.jcorpfin.2013.11.016

Lodh, S., Nandy, M., & Chen, J. (2014). Innovation and family ownership: Empirical evidence from India. *Corporate Governance: An International Review, 22*(1), 4–23. https://doi.org/10.1111/corg.12034

Luong, H., Moshirian, F., Nguyen, L., Tian, X., & Zhang, B. (2017). How do foreign institutional investors enhance firm innovation? *Journal of Financial and Quantitative Analysis, 52*(4), 1449–1490. https://doi.org/10.1017/S0022109017000497

Mangena, M., Tauringana, V., & Chamisa, E. (2012). Corporate boards, ownership structure and firm performance in an environment of severe political and economic crisis. *British Journal of Management, 23*(S1), S23–S41. https://doi.org/10.1111/j.1467-8551.2011.00804.x

Matoussi, H., & Jardak, M. K. (2012). International corporate governance and finance: Legal, cultural and political explanations. *The International Journal of Accounting, 47*(1), 1–43. https://doi.org/10.1016/j.intacc.2011.12.001

Mishra, A. V., & Ratti, R. A. (2011). Governance, monitoring and foreign investment in Chinese companies. *Emerging Markets Review, 12*(2), 171–188. https://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID1905287_code413010.pdf?abstractid=1505805

Musacchio, A., Lazzarini, S.G.,& Aguilera, R. V.(2015). New varieties of state capitalism:Strategic and governance implications. *Academy of Management Perspectives, 29*(1), 115–131.https://doi.org/10.5465/amp.2013.0094

National Development and Reform Commission. (2016). *The 13th five-year plan for economic and social development of the People's Republic of China (2016–2020)*. http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf

Nee, V., & Opper, S. (2012). *Capitalism from below: Markets and institutional change in China*. Harvard University Press.

O'Connor, M., & Rafferty, M. (2012). Corporate governance and innovation. *Journal of Financial and Quantitative Analysis, 47*(2), 397–413. https://doi.org/10.1017/S002210901200004X

Omar, N., Davidson, R., & Abdullah, N. (2016). Technology adoption in employee recruitment: The case of social media in Malaysia. *Journal of International Technology and Information Management, 25*(4), 1–24.

Osborne, J. W. (2012). *Best practices in data cleaning: A complete guide to everything you need to do before and after collecting your data*. Sage Publications.

Pallant, J. (2020). *SPSS survival manual: A step-by-step guide to data analysis using IBM SPSS* (7th ed.). McGraw-Hill Education.

Peng, M. W., Wang, D. Y. L., & Jiang, Y. (2008). An institution-based view of international business strategy: A focus on emerging economies. *Journal of International Business Studies, 39*(5), 920–936. https://doi.org/10.1057/palgrave.jibs.8400377

Peng, M. W., Zhang, S., & Li, X. (2007). CEO duality and firm performance during China's institutional transitions. *Management and Organization Review, 3*(2), 205–225. https://doi.org/10.1111/j.1740-8784.2007.00070.x

Peng, X. H., & Zhang, R. R. (2022). Corporate governance, environmental sustainability performance, and normative isomorphic force of national culture. *Environmental Science and Pollution Research, 29*, 443–473. https://doi.org/10.1007/s11356-021-15754-0

Ran, G., Fang, Q., Luo, S., & Chan, K. C. (2015). Supervisory board characteristics and accounting information quality: Evidence from China. *International Review of Economics & Finance, 37*, 18–32. https://doi.org/10.1016/j.iref.2014.10.009

Rauch, A., Wiklund, J., Lumpkin, G. T., & Frese, M. (2009). Entrepreneurial orientation and business performance: An assessment of past research and suggestions for the future. *Entrepreneurship Theory and Practice, 33*(3), 761–787. https://doi.org/10.1111/j.1540-6520.2009.00308.x

Rongping, M., & Wan, Q. (2008). The development of science and technology in China: A comparison with India and the United States. *Technology in Society, 30*(3–4), 319–329. https://doi.org/10.1016/j.techsoc.2008.04.004

Sahasranamam, S., Arya, B., & Sud, M. (2020). Ownership structure and corporate social responsibility in an emerging market. *Asia Pacific Journal of Management, 37*(4), 1165–1192. https://link.springer.com/article/10.1007/s10490-019-09649-1

Said, R. M., Zainuddin, Y., & Haron, H. (2020). The relationship between good governance and integrity system: Evidence from public sector organizations. *Journal of Financial Crime, 27*(3), 896–918. DOI:10.1108/H-02-2016-0008

Sanda, A. U., Mikailu, A. S., & Garba, T. (2010). Corporate governance mechanisms and firms' financial performance in Nigeria. *Afro-Asian Journal of Finance and Accounting, 2*(1), 22–39. https://doi.org/10.1504/AAJFA.2010.035193

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2012). *Research methods for business students* (6th ed.). Pearson.

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill-building approach* (7th ed.). Wiley.

Song, J.,Wang,R., & Cavusgil,S. T. (2015). State ownership and market orientation in China's public firms: An agency theory perspective.*International Business Review, 24*(4), 690–699. https://doi.org/10.1016/j.ibusrev.2014.12.003

Sorour, K. M., & Howell, K. E. (2013). A grounded theory analysis of corporate governance in Egyptian banking. *Qualitative Research Journal, 13*(3), 289–316. https://doi.org/10.1108/QRJ-05-2013-0032

Susskind, R., & Susskind, D. (2015). *The future of the professions: How technology will transform the work of human experts*. Oxford University Press.

Tapscott, D., & Tapscott, A. (2016). Blockchain revolution: How the technology behind Bitcoin is changing money, business, and the world. Portfolio.

Tidd, J., & Bessant, J. (2018). *Managing innovation: Integrating technological, market and organizational change* (6th ed.). Wiley.

Tsai, B. (2010). Analysis of patent and profitability in Taiwan semiconductor firms. In *Proceedings of PICMET 2010: Technology Management for Global Economic Growth* (pp. 1–6). IEEE. https://doi.org/10.1109/PICMET.2010.5603340

Wang, J. (2008). The strange role of independent directors in a two-tier board structure in China's listed companies. In J. Wang (Ed.), *Changing corporate governance practices in China and Japan* (pp. 185–205). Springer. https://doi.org/10.1057/9780230595156_9

Wang, J. M. (2021). Managing R&D in Chinese listed firms: The interactive effects of ownership concentration and corporate governance. *Thunderbird International Business Review, 63*(5), 607–621. https://doi.org/10.1002/tie.22207

Wang, Y., & Fan, W. (2014). R&D reporting methods and firm value: Evidence from China. *Chinese Management Studies, 8*(3), 375–396. https://doi.org/10.1108/CMS-01-2013-0019

Wiles, R., Crow, G., Heath, S., & Charles, V. (2008). The management of confidentiality and anonymity in social research. *International Journal of Social Research Methodology, 11*(5), 417–428. https://doi.org/10.1080/13645570701622231

Wintoki, M. B., Linck, J. S., & Netter, J. M. (2012). Endogeneity and the dynamics of internal corporate governance. *Journal of Financial Economics, 105*(3), 581–606. https://doi.org/10.1016/j.jfineco.2012.03.005

Xia, L., Gao, S., Wei, J. C., & Ding, Q. Y. (2022). Government subsidies and corporate green innovation: Does board governance play a role? *Energy Policy, 161*, 112120. DOI: 10.1016/j.enpol.2021.112720

Yang, L., Qin, H., Gan, Q., & Su, J. (2020). Internal control quality, enterprise environmental protection investment and financial performance: Evidence from China's A-share heavy pollution industry. *International Journal of Environmental Research and Public Health, 17*(2), 6082. https://doi.org/10.3390/ijerph17176082

Yang, L., Qin, H., Gan, Q., & Su, J. (2020). Internal control quality, enterprise environmental protection investment and financial performance: Evidence from China's A-share heavy pollution industry. *International Journal of Environmental Research and Public Health, 17*(17), 6082. https://doi.org/10.3390/ijerph17176082

Ye, Q., & Li, Z. (2017). Do independent directors play a political role? Evidence from independent directors' death events. *China Journal of Accounting Research, 10*(4), 295–316. https://doi.org/10.1016/j.cjar.2016.11.001

Yoshikawa, T., Zhu, H., & Wang, P. (2014). National governance system, corporate ownership, and roles of outside directors: A corporate governance bundle perspective. *Corporate Governance: An International Review, 22*(3), 252–265. https://doi.org/10.1111/corg.12050

Yu, M., & Ashton, J. K. (2015). Board leadership structure for Chinese public listed companies. *China Economic Review, 34*, 236–248. DOI: 10.1016/j.chieco.2015.01.010

Zhang, Y., & Li, W. (2021). The influence of technological innovation on corporate governance and firm performance. *Journal of Business Research, 123*, 57–67. https://doi.org/10.1016/j.jbusres.2020.09.051

Zhao, J. F., Pongtornkulpanich, A., & Cheng, W. J. (2022). The impact of board size on green innovation in China's heavily polluting enterprises: The mediating role of innovation openness. *Sustainability, 14*(2), 8692. https://doi.org/10.3390/su14148632

Zhou, K. Z., Gao, G. Y., & Zhao, H. (2017). State ownership and firm innovation in China: An integrated view of institutional and efficiency logics. *Administrative Science Quarterly, 62*(2), 375–404. https://doi.org/10.1177/0001839216674457

To cite this article: Wei Chiao Huang, XianXiang Lu, JiJian Gu, Pengyi Jia (2026). Launching the Journal of Financial and Economic Dynamics (JFED),Journal of Financial and Economic Dynamics, 1(1), 114-115; https://doi.org/10.66361/jfed.93

Editorial

Launching the *Journal of Financial and Economic Dynamics (JFED)*

Wei Chiao Huang[1], XianXiang Lu[2], JiJian Gu[3*], Pengyi Jia[4]

[1]*Wei Chiao Huang, College of Education and Human Development, Western Michigan University, 1903 W Michigan Ave, Kalamazoo, MI, 49008, USA; huang@wmich.edu*
[2]*XianXiang Lu, School of Economics, Zhongnan University of Economics and Law, 182 Nanhu Avenue, Wuhan 430073, P.R. China; lu010877@sina.com*
[3]*JiJian Gu, School of Economics and Management, Chongqing University of Arts and Sciences, 319 Honghe Avenue, Chongqing 402160, P.R. China; gumuran2006@126.com*
[4]*Pengyi Jia, School of Economics and Management, Chongqing University of Arts and Sciences, Chongqing 402160, P.R. China; pengyijia00313@outlook*
**Corresponding author: JiJian Gu, gumuran2006@126.com*

We are pleased to present the inaugural issue of the *Journal of Financial and Economic Dynamics (JFED)*, a peer-reviewed, open-access journal dedicated to advancing rigorous and impactful research on the evolving structures and processes that shape financial systems and economic development. At a time marked by rapid technological change, global interdependence, and increasing economic complexity, JFED seeks to provide a platform for scholarship that combines analytical depth with real-world relevance.

JFED is founded on the premise that contemporary challenges in finance and economics demand integrative, methodologically diverse, and forward-looking approaches. The journal aims to bridge theoretical inquiry and practical application, fostering dialogue across disciplines while maintaining the highest standards of academic rigor. By engaging scholars, practitioners, and policymakers worldwide, JFED aspires to contribute meaningfully to both intellectual advancement and informed decision-making.

Guiding the journal is a set of seven interrelated principles that define its editorial vision:

1.Truth-seeking underscores our commitment to intellectual integrity and the pursuit of reliable knowledge through careful reasoning and empirical validation.

2.Rationality emphasizes methodological rigor, logical coherence, and adherence to the highest standards of scholarly inquiry.

3.Thought reflects the importance of originality, critical reflection, and the development of new perspectives that advance understanding.

4.Passion recognizes the role of intellectual curiosity and sustained dedication in driving meaningful research.

5.Fertile ground represents our commitment to fostering an inclusive and supportive academic environment that welcomes diverse perspectives and emerging voices.

6.Humanity highlights the responsibility of scholarship to engage with societal challenges and contribute to human well-being.

7.Constructive dialogue affirms the value of open debate and the exchange of ideas as essential to scholarly progress.

Together, these principles form a coherent framework that supports innovative, responsible, and impactful research in finance and economics.

The journal adopts a broad and integrative scope, encompassing areas such as financial markets, corporate finance, macroeconomic dynamics, development economics, environmental and resource economics, and risk and investment analysis. We particularly encourage contributions that address complexity, adaptation, and structural change in economic and financial systems, and that employ interdisciplinary perspectives or novel methodologies.

JFED is guided by three core commitments:

●**Excellence in scholarship** — Upholding rigorous, transparent, and constructive peer review to ensure the highest academic standards.

●**Relevance and impact** — Promoting research that offers meaningful theoretical insights and practical implications for academia, industry, and public policy.

●**Accessibility** — Supporting the wide dissemination of knowledge through an open-access publishing model.

The inaugural issue features six articles that illustrate the journal's scope and aspirations. These contributions highlight three broad themes: methodological and theoretical innovation, the analysis of pressing real-world challenges, and the integration of micro- and macro-level perspectives. Collectively, they demonstrate how rigorous research can deepen understanding while addressing issues such as technological transformation, sustainable development, financial governance, and regional economic dynamics.

We welcome original research articles, review papers, and policy-oriented contributions from scholars and practitioners around the world. By fostering interdisciplinary dialogue and encouraging methodological innovation, JFED seeks to serve as a trusted venue for high-quality research that advances knowledge and informs practice.

The success of the journal will depend on the engagement of a global scholarly community. We warmly invite researchers, professionals, and emerging scholars to contribute their work and to participate in shaping the future of finance and economics through JFED.

We look forward to building a vibrant intellectual community and to establishing the *Journal of Financial and Economic Dynamics* as a leading platform for influential and forward-looking research.

Conflicts of Interest

The author declares no conflict of interest.