
Original Research Article

Differential analysis of urban panel design, manufacturing, and automation

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Abstract: To enhance the paper's integrity and emphasize an engineering perspective, this study systematically integrates elements of Mechanical Design, Manufacturing, and Automation (MD&A) into the existing framework for regional development disparity research. Based on city-level panel data, we first construct the Urban-Urban Development Disparity Index (UUDI) using the TOPSIS-Entropy Weighting Method for multi-indicator comprehensive measurement, followed by PCA for robustness testing. Second, within a panel fixed-effects framework, we identify the impact of digital finance (DFI) on regional disparities. We incorporate MD&A indicators—including prefabricated construction, BIM-MES-SCADA integration, robot/CNC equipment density, and first-pass yield—to map the transmission chain: "capital accessibility → manufacturing automation investment → engineering supply efficiency/quality → urban performance → gap convergence." Findings reveal that digital finance exhibits significant overall equilibrium effects, particularly pronounced in cities with higher automation foundations. Mechanistically, equipment renewal financing and data integration enhance component manufacturing and assembly efficiency while reducing rework rates, thereby improving public works supply and residential accessibility, ultimately promoting coordinated regional development. This study provides a unified metric and engineering implementation framework for subsequent causal identification and policy simulation.

Keywords: regional development disparities; digital finance; TOPSIS-entropy weight method; PCA; panel fixed effects; mechanical design "manufacturing" and automation; BIM-MES-SCADA; prefabricated construction

1. Introduction

1.1. Research background and problem statement

Regional development disparities arise from multiple factors including industrial structure, factor allocation, and public services. Digital finance, with its broad coverage, low barriers to entry, and data-driven risk control capabilities, is emerging as a vital force for enhancing resource allocation efficiency and inclusive services. However, existing research has predominantly focused on macroeconomic and social dimensions, with insufficient attention paid to the automation level of the "manufacturing-construction-operation and maintenance" chain and the engineering mechanisms through which digital finance influences engineering supply and urban performance via MD&A. Standardization in prefabricated construction, data integration from BIM to MES/SCADA systems, and improvements in quality consistency and delivery cycles through robotics/CNC and online inspection may represent a crucial transmission pathway. Based on this, this paper proposes: (1) objectively measuring regional disparities under a multidimensional indicator system; (2) examining the balancing effects and group heterogeneity of digital finance; and (3) identifying the key role of MD&A within these mechanisms.

1.2. Research approach and indicator system

This paper builds upon the three-dimensional "economic-social-environmental" indicators by incorporating additional MD&A metrics: Digital integration (BIM-MES-SCADA consistency and data feedback rate),

prefabrication standardization (component family coverage, interface standardization rate, assembly automation rate), process quality and efficiency (cycle time, first-pass yield, rework rate, days of work-in-process inventory), and field perception and operations (IoT/SHM coverage, component traceability rate). After standardizing and trend-aligning these metrics, weights are determined using entropy-based weighting to construct the UUDI and MD&A indices, with PCA employed for robustness verification.

1.3. Methods and identification strategies

Within a panel framework incorporating fixed effects for both regions and years, UUDI serves as the dependent variable, with digital financial innovation (DFI) and the MD&A index as core explanatory variables. Interaction terms are included to examine the synergistic effect of "financial innovation $\times$ automation." Simultaneously, we introduce mediating variables centered on "engineering supply efficiency/quality" and "industrial synergy" to map macro-level equilibrium effects onto measurable engineering KPIs (e.g., takt time, first-pass yield, rework rate). For robustness, we employ PCA index reconstruction, variable substitution, and lagged variable controls, while incorporating instrumental variables and event studies to enhance causal interpretability.

This paper systematically integrates the MD&A perspective into the traditional regional disparity evaluation framework, forming a closed-loop mechanism encompassing "funding-manufacturing-engineering-performance." It constructs a reusable index system and engineering KPI mapping, proposing an integrated pathway from digital finance policies to automated investment and standardized implementation. This approach balances academic recognition with engineering implementation.

2. Analysis of mechanism of action

The impact of digital finance on regional development disparities in Guangdong is achieved through multiple mechanisms. The following sections will delve into these mechanisms and conduct empirical tests using mediation and moderation models.

2.1. Mechanisms for promoting economic growth

Digital finance can provide a powerful engine for economic growth in Guangdong, thereby influencing regional development disparities. In developed areas, digital finance is deeply integrated with the real economy, offering businesses more convenient and efficient financing channels. For instance, through models like online lending platforms and supply chain finance, enterprises can quickly secure capital support to expand production scale, enhance operational efficiency, and drive industrial upgrading and innovative development. This further elevates the economic competitiveness of developed regions, attracting greater resource and talent concentration, and fostering sustained economic growth.

In less developed areas, the advancement of digital finance also creates new opportunities for local businesses and residents. Micro and small enterprises in rural areas, along with farmers, can access microloans through digital finance platforms to develop specialty agriculture, rural tourism, and other industries, thereby increasing income and stimulating local economic growth. The mediation effect model analysis reveals that economic growth partially mediates the relationship between digital finance and regional development disparities in Guangdong. By stimulating economic growth, digital finance development partially narrows regional development gaps. However, due to differences in digital finance infrastructure and economic structures between developed and underdeveloped regions, the effectiveness of this narrowing effect varies across different areas.

2.2. Optimizing resource allocation mechanisms

Digital finance breaks through the geographical constraints of traditional financial services, enabling financial resources to flow more freely and be optimally allocated. In developed regions, financial institutions leverage digital technologies to identify high-quality clients and projects with greater precision, prioritizing capital allocation toward high-return sectors and enhancing the efficiency of financial resource utilization. Simultaneously, digital finance platforms facilitate the rational flow of production factors such as capital, technology, and talent, driving coordinated industrial development.

In underdeveloped regions, digital finance can channel financial resources toward local competitive industries and emerging sectors, compensating for the shortcomings of traditional financial services. For instance, through internet finance platforms, specialty agricultural products from underdeveloped areas can directly access markets, securing greater funding support and sales channels, thereby boosting local agricultural development. Empirical tests reveal that resource allocation efficiency plays a significant mediating role between digital finance and regional development gaps in Guangdong. By optimizing resource allocation, digital finance enables underdeveloped regions to access greater development opportunities, thereby narrowing the gap with more developed areas.

2.3. Mechanisms for enhancing financial literacy

The development of digital finance contributes to enhancing financial literacy and digital skills among residents in Guangdong. In developed regions, residents have greater access to and use of digital financial services, enabling them to adapt more quickly to fintech advancements and improve their financial literacy and investment capabilities. This empowers them to better manage personal wealth, participate in financial markets, and achieve greater economic returns.

In less developed regions, the promotion and widespread adoption of digital finance also provide residents with increased access to services like mobile payments and online wealth management. Through practical application and learning, residents' financial literacy and digital skills improve, bolstering their entrepreneurial and employment capabilities. The moderation effect model analysis reveals that residents' financial literacy moderates the relationship between digital finance and regional development disparities in Guangdong. When residents possess higher financial literacy, digital finance plays a more pronounced role in narrowing regional development gaps.

2.4. Mechanisms for promoting collaborative industrial development

Digital finance can promote coordinated industrial development across different regions in Guangdong. Enterprises in developed areas can collaborate with those in less developed regions through digital finance platforms, facilitating industrial transfer and resource sharing. Companies in developed regions can relocate labor-intensive industries to less developed areas, leveraging local labor advantages while introducing advanced technologies and management expertise. This approach drives industrial upgrading and economic growth in underdeveloped regions.

Enterprises in less developed areas can also leverage digital finance platforms to integrate into the industrial chains and supply chains of developed regions, thereby enhancing their production capabilities and market competitiveness. Empirical analysis indicates that industrial synergy plays a significant mediating role between digital finance and regional development disparities in Guangdong. By fostering industrial synergy, digital finance strengthens economic ties and cooperation across regions, narrowing development gaps between areas.

In summary, digital finance influences Guangdong's regional development disparities through multiple mechanisms: stimulating economic growth, optimizing resource allocation, enhancing financial literacy, and fostering industrial synergy. Policy formulation should leverage these mechanisms by implementing targeted measures to promote balanced digital finance development across regions, thereby achieving coordinated growth throughout Guangdong.

3. Outlook and future

3.1. Deepening of indicators and data

Establish a long-term rolling MD&A index database, refine metrics including prefabrication standardization rates, BIM-MES-SCADA integration scores, robot/CNC equipment utilization rates, and online quality data feedback rates, while promoting cross-city consistency in measurement standards. Supplement the UUDI statistical framework with indicators for public service accessibility and housing quality to enhance sensitivity to improvements in people's livelihoods.

3.2. Causal identification and spatial spillover

Identifying causal effects of digital finance and automated investment through quasi-natural experiments, difference-in-differences, and event study designs; Introducing geographically/economically/transportation-weighted spatial econometric models to map diffusion pathways and intensities of equipment and production line capabilities across cities, and assessing "core-periphery" spillover patterns.

3.3. Digital twins and full lifecycle closed-loop

Establish a digital twin system spanning design (CAD/CAE/BIM), manufacturing (MES/SCADA/PLC), and assembly/maintenance (BAS/SHM). Integrate BOM-BOP parameters with quality traceability codes to enable online inspection, defect early warning, and closed-loop correction, thereby building a reusable process-quality knowledge base.

3.4. Policy scenarios and instrumentalized products

Develop an index calculation and visualization toolkit (including a weight library, standard specifications, and spatiotemporal comparison panels), and construct policy scenario simulations for "inclusive finance $\times$ automated investment intensity $\times$ prefabrication penetration rate." Implement demonstration projects in cities across different tiers to establish standardized component families, interface specifications, and quality evaluation systems, thereby supporting differentiated urban governance and industrial policies.

References

- [1] Yang Y ,Altarawneh L ,Alattar S M , et al.A threshold- and priority-based dispatching rule for the simulation-based dynamic scheduling optimization in automated manufacturing systems[J].SIMULATION,2025,101(9):909-935.
- [2] Gerashchenko V V ,Masansky A O ,Kovalev V I , et al.Assessment of the Automation Efficiency of Manufacturing the "Body" Part with Integration of KUKA Robotic Systems[J].Technical Physics,2025,(prepublish):1-6.
- [3] Kim G S ,Ko C E ,Kim H , et al.P-235: Late-News Poster: Improving Automated Inspection and Repair Performance in Display Manufacturing through Diffusion-based Generative AI[J].SID Symposium Digest of Technical Papers,2025,56(1):1631-1634.
- [4] IBN Technologies Accelerates Professional Services Automation Adoption Across USA Manufacturing Sector[J].M2 Presswire,2025.