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Dilemmas and pathways for the integration of the digital economy in private economy-dominated industrial clusters: an analysis based on Quanzhou's nine major industrial clusters

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Abstract. The deep integration of the digital economy with traditional industries constitutes a core pathway for the high-quality development of manufacturing. Taking Quanzhou's nine major industrial clusters as the research object, this study employs a combination of field investigation and cross-regional comparative analysis to systematically examine the current state of digital-industrial integration from four dimensions: integration foundation, service ecosystem, demonstration effects, and integration outcomes. The analysis identifies three major contradictions: the asymmetry between full-scale coverage and efficiency transformation, the disconnect between leading-firm-driven development and systemic diffusion transmission, and the structural mismatch between ecosystem building and the depth of collaborative integration. In response to the characteristics of Quanzhou's private economy and its industrial endowments, this study constructs an adaptive development pathway system for digital-industrial integration from four dimensions—inclusive empowerment, technological adaptation, whole-chain coordination, and policy support. It further proposes specific implementation strategies, including a private economy-oriented inclusive empowerment system, a technology adaptation ecosystem guided by specialized industries, a full industrial chain data collaboration mechanism, and a precision-oriented policy implementation and governance framework.

Keywords: digital economy, traditional industries, industrial integration, development pathways, Quanzhou City

1. Introduction

At present, the digital economy has become a core engine driving China's high-quality economic development, while the digital transformation of traditional industries is accelerating nationwide and has emerged as a crucial lever for building a modern industrial system [1]. However, due to differences in industrial foundations and economic structures across regions, transformation pathways and the challenges encountered exhibit significant divergence. Compared with cities such as Suzhou and Ningbo, where high-end manufacturing and export-oriented economies dominate, Quanzhou—characterized by a private economy-led structure supported

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by nine major traditional industrial clusters—faces more distinctive challenges in digital transformation. These include a high proportion of private Small and Medium-sized Enterprises (SMEs), limited capacity for technological investment, and insufficient inclusiveness in industrial digitalization, making it difficult to simply replicate the experiences of more advanced cities.

The integration of the digital economy and manufacturing has become a major focus in academic research, with existing studies primarily unfolding along three dimensions. At the macro level, research has concentrated on the driving mechanisms, measurement systems, and policy pathways of integrated development, demonstrating the role of digital technologies in enhancing total factor productivity in manufacturing [2]. Some scholars have developed an "input–process–output" full-chain measurement framework to systematically assess the effectiveness of manufacturing digital transformation [3]. Other studies, from perspectives such as data factor flows and technological innovation diffusion, have revealed the intrinsic mechanisms through which the digital economy drives industrial chain upgrading in manufacturing [4], thereby providing theoretical support for national industrial digitalization policies [5]. At the meso level, research has focused on the digital transformation of industrial clusters, analyzing the critical role of leading enterprises' demonstration effects and collaborative transformation among SMEs, while highlighting differentiated transformation trajectories across regions due to disparities in industrial foundations [6]. Studies generally argue that leading enterprises, through models such as chain-based empowerment and platform openness, constitute the core force driving coordinated transformation among SMEs within clusters [7]. However, heterogeneity in regional industrial foundations and cluster ecosystems often leads to significant divergence in transformation outcomes [8], while hierarchical disparities among large, medium, and small enterprises may obstruct the diffusion and transmission of transformation achievements [9]. At the micro level, enterprise case studies have examined technology selection in digital upgrading, performance evaluation, and the financial and human capital constraints faced by SMEs. Empirical studies show that insufficient capital investment and limited financing channels are the primary bottlenecks hindering SMEs' digital transformation [10]. Meanwhile, shortages of interdisciplinary digital talent and lagging talent development further constrain the depth and sustainability of enterprise transformation [11, 12].

Existing studies on cities characterized by "private economy dominance and dense traditional industries" have largely focused on the national level, while systematic cross-regional comparative research specifically centered on Quanzhou remains insufficient. Current studies mostly discuss digitalization practices in individual industries or leading enterprises, affirming achievements in industrial digital exploration while also noting the lagging transformation of SMEs [13]. However, the literature has yet to establish an integration evaluation framework suited to such regions, nor has it provided empirically grounded differentiated pathway designs. Based on this gap, this study raises three research questions: (1) What are the current characteristics and core contradictions of digital-industrial integration in Quanzhou? (2) Compared with advanced cities, what are the underlying mechanisms behind Quanzhou's gaps? (3) How can an integration development pathway be designed to suit private economy-dominated industrial clusters?

To address these questions, this study takes Quanzhou's traditional industrial clusters, including textiles and footwear, as well as building materials and home furnishing, as research objects. Closely aligned with national and Fujian Province digital economy development strategies, it employs a combination of big data collection, field investigation, and cross-regional comparative analysis to construct a three-dimensional evaluation framework encompassing technological integration, model innovation, and economic performance. Data are mainly drawn from official digital economy reports of Quanzhou and Fujian Province from 2023 to 2025, statistical yearbooks, digital transformation monitoring data for SMEs, and frontline enterprise survey materials. Based on these data, the study systematically analyzes the current status of integration development,

identifies gaps and core dilemmas relative to advanced cities, and ultimately proposes a development pathway tailored to local characteristics.

2. Current status and characteristics of the integration of the digital economy and traditional industries in Quanzhou

2.1. Foundation for integration

2.1.1. Significant progress in policy and infrastructure support

A sound policy support system has been established in Quanzhou. A series of policy documents, including the *Three-Year Action Plan for Digital Economy Development in Quanzhou*, have been issued, and in 2024 Quanzhou was selected as a "National Pilot City for SME Digital Transformation" [14]. This has gradually formed an overall integration pathway characterized by "infrastructure foundation → equipment connectivity → data interconnection → intelligent optimization → ecosystem collaboration".

Remarkable achievements have also been made in digital infrastructure construction. Quanzhou has built the largest 5G network and full-coverage gigabit fiber network in Fujian Province, with 25,000 5G base stations, ranking first in the province. The Maritime Silk Road Time Center provides sub-nanosecond-level time benchmarks, while the digital economy industrial park has reduced its Power Usage Effectiveness (PUE) to 1.06, placing it among the world's leading data centers in terms of energy efficiency.

2.1.2. Initial emergence of industrial agglomeration effects

Quanzhou has concentrated efforts on digital transformation by establishing three provincial-level core digital economy industrial concentration zones and promoting the development of a "one county, one digital economy cluster" model. From 2022 to 2024, the numbers of enterprises selected as innovative firms in Fujian's core digital economy sectors reached 17, 27, and 28 respectively [15]. The coverage rate of "intelligent upgrading and digital transformation" among above-scale enterprises in the city's nine major industrial clusters has reached 93%.

2.1.3. Gradual improvement of the local service ecosystem

Quanzhou has actively introduced and cultivated digital service resources. Through the attraction of 27 industrial internet platforms, it has built a "Digital Supermarket" linking more than 6,100 above-scale enterprises with digital service providers. It has also established an "Industrial Doctor" think tank resource pool and digital skills training bases, while collaborating with 30 research institutions. As a result, a transformation ecosystem involving 216 digital service providers has taken shape, offering low-cost diagnostic services and standardized solutions to more than 1,000 enterprises. Each year, the city trains 5,000 digital professionals in areas such as AI and chips, while helping enterprises solve over 2,000 technical challenges.

2.2. Integration outcomes

2.2.1. Remarkable achievements in digital transformation among leading enterprises

Within the nine major industrial clusters, leading enterprises have taken the lead in deeply embedding digital technologies such as 5G, industrial internet, and artificial intelligence, generating two representative demonstration mechanisms.

The platform-based collaborative model represented by Xintai Technology and Anta Group has established 5G-enabled industrial internet platforms, shortening footwear and apparel design cycles by 45% and reducing defect rates to 1.2%. Through industrial internet collaboration platforms, footwear production yield has

increased to 95%, while order response speed has improved by 35%. The key lies in integrating data across the entire chain of design, production, and supply, thereby enabling refined management.

The digital twin empowerment model represented by Jomoo Group and Hui'an stone carving has likewise delivered notable results. China's first 5G smart ceramics industrial park has reduced labor demand by 50% and increased smart toilet production efficiency by 35 percentage points. Meanwhile, the "Stone Cloud Warehouse" platform has shortened design cycles from seven days to eight hours and raised raw stone utilization rates from 30% to 85%, achieving full-process visualized management through digital twin technologies [16].

2.2.2. Steady expansion in coverage but insufficient depth of integration

By 2024, more than 6,800 enterprises in Quanzhou had completed digital transformation, while the number of national-level 5G factories and provincial demonstration projects ranked first in Fujian Province [17]. However, the depth of transformation reveals marked structural disparities. Core benefits remain concentrated in a limited number of firms, and broad-based inclusive effects across industries have yet to fully emerge. As shown in Table 1, substantial differences exist in the depth of digital advancement among different types of enterprises.

Table 1. Comparison of digital transformation structures and outcomes among different types of enterprises in Quanzhou

Type of Digital Transformation	Share of Enterprises	Transformation Characteristics	Actual Outcomes	Enterprise Type
Single-point equipment upgrading	Approx. 80%	Limited to equipment connectivity and localized process automation, without full-process data integration	Improves only individual links, with no significant effect on cost reduction or delivery-cycle shortening	Mainly SMEs and some below-scale traditional manufacturers
Full-process digital transformation	Approx. 20%	Integrates data across design, production, supply chain, and marketing, enabling data-driven full-process management	Production efficiency increases by 15%–30%; operating costs fall by 12%–20%; defect rates and delivery cycles are optimized	Leading enterprises and key above-scale backbone firms

At the overall industrial level, the core benefits of digital transformation in the nine major industrial clusters are largely driven by the 20% of enterprises that have achieved full-process integration, contributing to improvements in production efficiency and reductions in operating costs across industries. Coverage in various subsectors has steadily increased: digital transformation coverage has reached 62% in the textile and footwear industry, 65% in Hui'an stone carving, and over 60% digital quality-control coverage in the food and beverage sector. However, it should be noted that approximately 80% of enterprises engaging only in single-point upgrading can achieve efficiency gains only in localized processes and cannot realize full-process cost reduction and efficiency enhancement. The collaborative empowering effects across the entire industrial chain —from R&D and production to circulation and marketing—have yet to be fully unleashed. Although the digital economy has become a core driver of high-quality regional economic development in Quanzhou, its empowering value has not yet achieved universal benefits across all industries [18].

2.3. Gaps in integration

2.3.1. Shortcomings in the conversion of infrastructure efficiency

Although Quanzhou has established the largest 5G network and full-coverage gigabit optical network in Fujian Province, the actual utilization rate of 5G industrial application scenarios among SMEs remains below 40% [19]. A substantial amount of network resources has yet to be effectively transformed into productive efficiency. High-computing-power resources are largely concentrated in leading enterprises, while small and micro enterprises face difficulty accessing shared computing resources at low cost. As a result, the technological dividends generated by digital infrastructure have not effectively penetrated the broader SME sector. This stands in sharp contrast to cities such as Ningbo and Suzhou, where inclusive access to computing power and widespread application scenarios have been promoted through intensive platform-based models.

2.3.2. Distinctive divergence in industrial transformation

Quanzhou exhibits a pronouncedly differentiated pattern of digital transformation, with innovation activities highly concentrated in competitive sectors such as textiles and footwear, while traditional industries such as building materials and food face a notable shortage of digital innovation supply. The coverage rate of digital transformation among below-scale micro and small enterprises remains below 30%, reflecting a pattern in which "large enterprises lead while small and micro enterprises lag behind". Compared with the mature Customer-to-Manufacturer (C2M) customized production models and full-chain collaborative industrial ecosystems found in Ningbo and Suzhou [20], most traditional enterprises in Quanzhou still rely predominantly on conventional production models, with a low share of customized manufacturing and insufficient cross-enterprise data sharing. This stems largely from the pronounced characteristics of Quanzhou's private economy, which is marked by small scale, fragmentation, and heterogeneity. Many firms operate under family-style management, and business owners often show limited willingness to share data, resulting in a fragmented pattern in which enterprises operate in isolation. Moreover, the lack of platform-oriented enterprises capable of leading and connecting the "demand–production" chain has made it difficult for customized production models to scale, while the radiating effect of a "chain leader-driven plus cluster-wide inclusive empowerment" model has yet to be fully realized.

2.3.3. Significant gap in technology application compared with advanced cities

The proportion of enterprises applying cloud-based collaborative manufacturing in Quanzhou is only 42% of that in Ningbo and Suzhou. The penetration of digital twin technologies in production line upgrading lags by approximately 1.8 generations, while the per capita installation of industrial applications in the textile and apparel sector stands at only 0.7 apps per person, far below Ningbo's 2.3 per person. This gap stems not only from the relatively weak service capabilities of local industrial internet platforms, high dependence on external technologies, and the fact that digital technology penetration remains largely confined to single-point equipment upgrades, but also from structural shortcomings in infrastructure efficiency release and industrial digital transformation. These factors have widened the disparity between Quanzhou and advanced cities in terms of the breadth, depth, and inclusiveness of digital technology applications.

2.3.4. Growing transformation barriers for small and micro enterprises

Although digital transformation solutions adopted by leading enterprises have yielded significant results, small and micro enterprises continue to face major constraints, including limited financial endowments, barriers in technological adaptation, shortages of skilled personnel, and insufficient ecosystem collaboration. As a consequence, the digital divide within industries continues to widen [21]. In sectors such as craft products and petrochemicals, while leading enterprises have achieved cost reductions and efficiency gains, the overall digital penetration rate of these industries remains heavily dependent on a small number of leading firms.

Digital dividends have not yet been effectively transformed into endogenous drivers for upgrading the entire industrial chain. As a result, the inclusiveness and systemic effectiveness of industrial integration have yet to be fully unleashed.

3. Core problems in the integrated development of the digital economy and traditional industries in Quanzhou

Based on survey data and cross-regional comparative analysis, three core contradictions have emerged in the integration of the digital economy and traditional industries in Quanzhou, constituting the principal bottlenecks hindering deeper integration.

3.1. The asymmetrical contradiction between broad coverage and efficiency conversion

Although Quanzhou possesses clear advantages in the scale of digital infrastructure, the allocation of factor resources exhibits structural bias, resulting in disparities in the efficiency of network and computing resources between leading enterprises and small and micro enterprises. This structural imbalance in resource allocation, coupled with the fact that digital technologies remain largely confined to shallow integration at the level of single-point equipment optimization, has constrained deeper penetration across all factors and the full production process. Consequently, the advantages of scale have not been effectively translated into improvements in overall industrial productivity, giving rise to an asymmetrical contradiction between broad-based coverage and efficiency conversion.

3.2. The contradiction of transmission blockages between leading-firm guidance and system-wide diffusion

Leading enterprises in Quanzhou have already developed relatively mature digital transformation models. However, differences in financial resources, levels of technological adaptation, and talent reserves have hindered the effective transmission of transformation outcomes to small and micro enterprises. The mismatch in developmental levels among market actors, together with disruptions in transmission pathways, has produced a coexistence of "clear head-end demonstration effects" and "weak tail-end breakthroughs". As a result, hierarchical linkages across the entire industrial chain have failed to effectively diffuse and convert digital dividends, creating a contradiction marked by transmission blockages between leading-firm guidance and system-wide diffusion.

3.3. The structural mismatch between ecosystem building and the depth of collaboration

Although an initial digital service supply system has taken shape, it remains structurally misaligned with the practical needs of enterprises operating within the "small, fragmented, and heterogeneous" characteristics of Quanzhou's private economy. The standardized orientation of the service supply system does not adequately match the personalized and fragmented demands of small and micro enterprises. At the same time, cross-entity data barriers continue to obstruct the effective connection and integration of the full "demand–production" collaborative chain. As a result, the systemic empowering capacity of the service ecosystem fails to align with the practical demands of industrial chain collaboration, giving rise to a structural mismatch between ecosystem building and the depth of collaborative integration.

4. Path selection for the integrated development of the digital economy and traditional industries in Quanzhou

4.1. Building an inclusive empowerment system adapted to the private economy to alleviate transformation constraints for small and micro enterprises

Given the characteristics of Quanzhou's private economy—small-scale enterprises, dispersed distribution, and relatively loose organizational structures—it is necessary to build a lightweight and low-cost digital service supply system. Modular and cloud-based software services, together with flexible transformation solutions, should be promoted, while customized SaaS applications tailored to characteristic industries such as textiles and footwear, building materials, and home furnishing should be developed to lower initial transformation costs and technological adaptation barriers. Relying on chain-leading enterprises, industry-level industrial internet platforms should be established to open foundational functions such as equipment connectivity and production scheduling, thereby forming a chain-based transmission mechanism in which leading firms drive SMEs forward. At the same time, the digital skills training system should be improved by providing inclusive training programs for small business owners and industrial workers, addressing deficiencies in grassroots digital capabilities and gradually narrowing the digital divide among enterprises.

4.2. Developing a characteristic industry-oriented technology adaptation ecosystem to strengthen local innovation supply capacity

Focusing on the mismatch between general digital technologies and the needs of Quanzhou's characteristic industries, it is essential to build an ecosystem for technological innovation and application transformation in vertical sectors. Service providers should be encouraged to develop specialized digital systems tailored to scenarios such as multi-variety, small-batch production in textiles and footwear, and customized production in building materials and home furnishing, thereby replacing generic MES and ERP systems to overcome adaptability limitations. Collaboration among industry, academia, research, and application should be deepened through joint efforts by universities and research institutions to establish "industry + technology adaptation" laboratories. This would promote the deep integration of technologies such as digital twins and 5G collaboration with characteristic industrial processes, generating replicable industry solutions. Meanwhile, cultivating local digital service providers can enhance their understanding of indigenous industrial processes and improve service responsiveness, while reducing dependence on external technologies.

4.3. Improving full industrial chain data collaboration mechanisms to unlock the integration value of the private economy

Taking the circulation of data factors as a core breakthrough point, efforts should be made to address fragmentation in industrial chain data and insufficient value spillover. This requires promoting the integration of internal enterprise data resources and the restructuring of business processes, breaking down internal data barriers, and enabling digital control and intelligent scheduling across the entire business chain. At the same time, connectivity and business collaboration across upstream and downstream industrial chain actors should be strengthened. Core enterprises should be supported in establishing supply chain collaboration platforms to realize real-time sharing of order, production scheduling, and logistics information, thereby improving the operational efficiency, resilience, and flexibility of industrial clusters. Cross-industry integration and application of data factors should also be advanced, expanding coordinated scenarios such as textiles and footwear linked with e-commerce livestreaming, and building materials and home furnishing linked with

smart home decoration. In this way, data can drive both value chain extension and optimization of value structures.

4.4. Optimizing precision-oriented policy implementation and governance systems to safeguard integrated development in the private economy

A policy implementation and governance mechanism suited to the characteristics of Quanzhou's private economy should be established. Procedures for applying for digitalization subsidies should be simplified to reduce thresholds for small and micro enterprises, ensuring direct and efficient access to policy funds and improving enterprises' sense of policy accessibility. Differentiated policy support strategies should be implemented, with greater emphasis placed on traditional industries and weak links in transformation, thereby optimizing the efficiency of policy resource allocation. At the same time, a sound system for data security governance and incentives for data sharing should be developed to lower the transaction costs of data sharing and exchange among enterprises. This would promote deeper collaboration among industry, academia, research, and application, fostering a healthy integration ecosystem characterized by government guidance, market leadership, and enterprise participation.

5. Conclusion and prospect

5.1. Research conclusions

This study shows that Quanzhou possesses a solid industrial foundation and favorable institutional conditions for integrating the digital economy with traditional industries, while also facing practical challenges such as transformation constraints, insufficient technological adaptation, weak data collaboration, and governance effectiveness yet to be enhanced. Based on the characteristics of Quanzhou's private economy and specialized industrial clusters, this study proposes targeted pathways for integration development. Through the construction of an inclusive empowerment system, a technology adaptation ecosystem, data collaboration mechanisms, and precision-oriented governance support, it aims to promote deeper development of digital-industrial integration. The findings provide both theoretical support and practical guidance for the high-quality digital transformation of Quanzhou's industries, while also offering useful reference for the digital transformation of similar traditional industrial agglomeration regions.

5.2. Future prospects

Future research may further focus on inclusive mechanisms for the digital transformation of private small and micro enterprises in Quanzhou, while improving cross-domain data collaboration and technological innovation systems suited to local characteristic industrial clusters. Such efforts can provide more targeted theoretical references and practical solutions for regional digital-industrial integration.

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