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Leveraging Local Standards for Systemic Innovation: How Internationalization Strategy Amplifies Radical Innovation in Manufacturing Business Systems

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Abstract

Systemic innovation is restructuring global industrial competition. This study focuses on the relationships between local product standards, firm internationalization, and radical innovation. Using panel data of Chinese listed manufacturing firms from 2005 to 2017, this paper empirically examines how local product standards shape corporate radical innovation and its underlying mechanisms, as well as the moderating role of firm internationalization. The results show that local product standards facilitate radical innovation through three key channels: regional knowledge spillovers, fair market competition, and cross-regional market integration. Firm internationalization positively strengthens the innovation-promoting effect of local product standards. Furthermore, heterogeneity analysis suggests that such beneficial effects are more salient for firms with low digital transformation, weak business credit, and those in non-high-tech industries.

Keywords: local standards; systemic innovation; firm internationalization; manufacturing business systems; radical innovation

1. Introduction

The global economy is undergoing a critical transformation driven by innovation-led competition. Technologically advanced countries seek to consolidate their industrial advantages by tightening technical standard barriers [1]. Global manufacturing competition has accordingly evolved from product-based rivalry to competition centered on industrial standards and innovation ecosystems. After years of development, China's economy has entered a high-quality development stage. Breaking long-term technological bottlenecks and achieving independent and controllable industrial chains have become core development priorities [2]. Nevertheless, Chinese manufacturing firms still face prominent dilemmas, including insufficient innovation motivation, limited radical innovation output, and low technology commercialization efficiency. Effective policy tools are therefore urgently required to guide and regulate corporate innovation activities.

Against this backdrop, local standards serve as critical regional institutional arrangements that bridge national macro policies and corporate micro behaviors. Their strategic value has become increasingly prominent. The mid-term evaluation report of China's National Standardization Development Outline (2025) shows that the number of local standards in China has exceeded 120,000. These standards cover key manufacturing sectors, such as equipment manufacturing and new materials, and have become core instruments



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for regional industrial coordination and technical regulation. Unlike unified national standards and universal international standards, local standards feature strong regional adaptability. They precisely match the technical endowments and practical bottlenecks of local manufacturing industries, and help resolve firms' innovation dilemmas, such as unclear innovation directions and excessive innovation costs. According to a survey by the Ministry of Commerce of China, 62% of manufacturing firms experienced prolonged technology transformation cycles in 2024 due to inconsistencies between domestic and foreign standards. Meanwhile, 38% of firms encountered overseas compliance barriers due to the lack of supportive regional standards. Furthermore, firm internationalization has become a vital approach for manufacturers to improve innovation capabilities. An increasing number of Chinese manufacturing firms have achieved technological upgrading through technology introduction and collaborative overseas research and development. Growing practical evidence indicates that the synergy between local standards and firm internationalization is key to breaking the innovation isolation effect.

However, existing research pays limited attention to the innovation effects of local standards. Most studies focus on national or international standards while neglecting provincial local standards tailored to regional industrial characteristics. In the Chinese context, provincial local standards are essential for the formation and sustainable operation of regional manufacturing ecosystems [3]. The lack of relevant research hinders a comprehensive understanding of corporate innovation development. From the knowledge-based view and resource dependence theory, existing work tends to examine corporate innovation and resource acquisition separately. Few studies systematically link local standards, firm internationalization and radical innovation. This study constructs an analytical framework based on general systems theory to address the defects of traditional research [4]. Traditional studies examine relevant factors in isolation and fail to explore how firms' global strategies interact with local institutional rules to shape radical innovation, thereby are unable to fully explain the dynamic relationships between regional institutions, corporate strategies and innovation performance.

Against this backdrop, this paper addresses three core research questions from a systematic perspective. First, can local product standards, as core regional institutional elements, promote radical innovation in manufacturing firms? Second, what are the inherent systemic mechanisms underlying this causal relationship? Third, can firm internationalization, as a crucial business strategy, strengthen the positive effects of local standards on radical innovation?

This study offers three key marginal contributions. First, it establishes a systematic analytical framework for the impact of local standards on corporate radical innovation for the first time. The framework organically integrates local institutional supply, global strategic layout and innovation outputs. It reveals how institutional rules reshape systemic operating environments and how internationalization embeds global resources into local systems to jointly drive radical innovation. This study enriches standard economics research at the regional level and provides a new perspective for understanding the interaction between institutional arrangements and micro-level innovation. Second, this study analyzes corporate radical innovation from both quantity and quality dimensions, making up for the insufficient attention paid to innovation quality in existing research. Third, this study takes firm internationalization as a moderating variable and divides it into internationalization breadth and depth to investigate differentiated moderating mechanisms [5,6]. It extends research on the boundary conditions of institutional effects associated with standards and explores an innovation synergy model combining local standards and global resources. This paper provides theoretical support for Chinese manufacturing firms to enhance their global competitiveness amid intensifying technological competition.

2. Literature Review

2.1. Standards and Innovation in Business Systems

2.1.1. The Innovation Effects of Standards

Drawing on systems theory, local standards act as institutional boundary objects that mitigate uncertainty and coordinate diverse stakeholders within regional innovation ecosystems. From the perspective of institutional economics, standards reduce transaction costs and alleviate information asymmetry, establishing a sound foundation for sustained innovation investment. Integrating these two theoretical perspectives, this study conceptualizes local standards as both coordinative mechanisms and institutional carriers of knowledge diffusion.

Early academic investigations into standardization and innovation primarily concentrated on the macroeconomic functions of standards as public goods in the economic operation system. Scholars have contended that standards can cut down transaction expenses and mitigate information asymmetry, which lays a solid institutional groundwork for innovation activities in business systems [7]. From the perspective of uncertainty management, scholars note that standards shape firm innovation by establishing orderly operational systems [8]. In terms of international trade, other studies demonstrated that the influence of quality standards on corporate export performance is contingent upon enterprises' compliance capabilities and internal innovation investments in their business systems [9].

A growing body of research has also discussed standardization issues at the regional level, with an emphasis on the function of standards in regional innovation ecosystems. Existing studies have proven that industrial standards optimize regional innovation systems through coordinating inter-enterprise resource distribution [10]. Another strand of literature verified that firm-level standard adoption contributes to the technological upgrading of internal business systems [11]. From the lens of system theory, standards serve as an effective coordination mechanism to unify the behavioral strategies of diverse stakeholders in business operation systems [12].

Subsequent studies began to differentiate the heterogeneous impacts of various standard types on business system innovation, among which environmental standards have become a prevailing research hotspot. Empirical evidence indicates that environmental regulations drive enterprises to optimize production procedures and further promote green innovation for sustainable business development [13,14]. Based on firm-level statistical data from Luxembourg, prior research validated that the ISO 14001 certification helps enterprises incorporate environmental management into business systems, thus boosting the industrialization of innovative achievements [15]. Environmental and managerial standards may create systemic rigidity and hinder firm-level innovation [16].

Moreover, the long-term effects of technical standards on business system innovation have drawn widespread scholarly attention. A study based on British manufacturing data shows that technical standards drive incremental innovation. But systemic path dependence will reduce firms' willingness to pursue radical innovation [17]. Consistent findings have been obtained in the communication industry, where IoT innovation relies heavily on unified communication standards to guarantee systematic compatibility among different modules [18].

Contemporary research further emphasizes the intricate correlation between standards and innovation in business systems. Academics proposed that standards lower technological and legal uncertainties; hence, industries with sound standard systems enable auxiliary enterprises to generate high-value innovative outcomes within business ecosystems [19]. Additionally, scholars identified a compatibility conflict between domestic patents and international standards in business systems. Although patents and standards can indepen-

dently facilitate innovation, their joint application may trigger path dependence and restrict firms' exploratory innovation behaviors [20]. Further research revealed that the iterative updating of technical standards requires enterprises to dynamically optimize patent strategies in innovation systems. For industries with frequent standard iterations, refined patent portfolios are conducive to improving overall innovation quality [21]. Current studies also highlight that differentiated regional standards generate diverse innovation incentives for manufacturing firms [22]. Stakeholder participation in standard-setting further optimizes the institutional environment for systemic innovation [23]. Beyond the direct incentive effect, the standard formulation acts as an important signaling and substantiating mechanism for internal knowledge integration, and its influence on corporate innovation varies across different development stages of enterprises [24].

2.1.2. Impacts of Local Standards on Innovation in Business Systems

Knowledge diffusion and network effects constitute two core systemic pathways through which standards affect innovation activities within business systems [1]. In terms of knowledge dissemination, international standards serve as a shared technical language that unifies industrial consensus. They lower the cost of accessing technical information and speed up knowledge spillovers across industrial ecosystems [25]. Taking the ISO 9000 certification as a typical example, prior research has proven that quality management systems can systematize internal knowledge, thereby optimizing the overall innovation efficiency of enterprises [26].

Follow-up studies further highlighted the essential role of international standard unification in facilitating systemic knowledge dissemination. Homogeneous standard frameworks are conducive to smoother knowledge circulation, particularly for technology-intensive industries that require high-level systemic coordination [27]. Besides knowledge diffusion, network effects act as another core transmission mechanism. Studies on communication technology show that integrated and iterated standards produce strong network externalities, driving innovation upgrading across the whole industrial ecosystem.

Examining ICT, relevant studies argued that standards coordinate different technical systems and facilitate inter-firm collaboration and resource sharing within the business network [28]. Other scholars extended this argument to environmental standards, showing that clusters of firms adhering to uniform standards are more likely to form knowledge networks and accelerate process innovation within the regional business system [14]. Related research similarly found that when most firms adopt the same standard, invisible collaborative networks emerge, fostering complementarity and joint R&D within the business ecosystem [29].

More recent studies focus on the concrete benefits of firm participation in standardization within their business systems. Based on emerging-market firms, existing literature showed that the dynamic interaction between internationalization and innovation relies on standards as network nodes, which strengthen knowledge flows and collaborative innovation within the global–local business system [30]. Further research argued that firms participating in standard-setting not only shape the direction of technological development but also gain access to tacit knowledge resources in committees, enhancing their systemic innovation capabilities [31]. As core nodes of industrial ecosystems, local standards accelerate knowledge circulation and collective innovation across regional enterprises [4].

2.2. Firm's Internationalization as a Strategic Component of Business Systems

Research on the impact of standards on firm internationalization within business systems is relatively limited, partly because it is difficult to match the classification of standards with firms' main businesses [32]. Most studies therefore focus on the effects

of standards on international trade, a key component of the firm's internationalization strategy within the global business system. On the import side, relevant studies found that mandatory certification standards improve import quality through the intensive margin but have a limited effect on creating new trade relationships within the global supply system [33].

On the export side, existing research found that the interaction of domestic patents and international standards may weaken the advantages of technological uniqueness within the global business system [20]. In general, the positive effects of standard harmonization, or the adoption of international standards, include reducing information asymmetry and enabling communication through a common technical language within the global business network. The negative effects stem from the costs of compliance, which can increase systemic burdens for firms.

The net effect depends on which force dominates firm operations [34]. Related studies have discussed the application of international standards, including ISO 14000 and ISO 9000 [34–36]. Other research focused on differences across countries and industries within the global business system.

From a national perspective, relevant studies found that adopting international standards helps developing countries overcome barriers to developed markets within the global business system [37], while other research pointed out that the rise of Southern standards is reshaping the Northern-dominated order [38]. From an industry perspective, existing literature showed that standard harmonization in sectors such as electronics, agriculture, clothing, and textiles improves foreign market access within the industry's global business system [39]. Related studies developed a model to quantify the contribution of standard harmonization, finding that harmonized standards increase global trade growth by 13% by reducing systemic frictions [32]. Home-country institutional arrangements represented by local standards profoundly shape firms' overseas expansion decisions and external knowledge acquisition [5]. It also redefines the boundary between institutional constraints and international strategic choices [6].

2.3. Internationalization and Innovation in Business Systems

With the expansion of multinational firms, internationalization has become an important way to obtain domestic and overseas resources. It supports corporate development and innovation in global business networks [40]. From a system theory perspective, the internationalization process embeds individual corporate business systems into global industrial ecosystems, promoting cross-border resource mobility and knowledge interchange [41]. Most academic studies have confirmed that the linkage between internationalization and innovation is dynamic and reciprocal, originating from continuous knowledge accumulation and capability cultivation at the firm level.

Such capability evolution comprises procurement competence for capturing overseas technological resources and absorptive capacity for consolidating internal and external knowledge assets within business systems [42,43]. Enterprises with superior absorptive capacity are more capable of transforming externally acquired market information into tangible innovative achievements.

Contemporary literature further identifies a circular interactive association between internationalization and innovation. Based on empirical evidence of Chinese manufacturing firms, scholars summarized a progressive development logic: "internationalization → innovation investment → innovation performance → deeper internationalization", forming a self-reinforcing closed-loop mechanism [30]. Other research indicated that access to cutting-edge technologies in global markets stimulates firms' innovation willingness, and the generated technological achievements can, in turn, consolidate their international com-

petitive advantages [20]. Existing empirical evidence also verifies that internationalization serves not merely as a resource acquisition approach but also as an effective driving factor for the improvement of corporate innovation capabilities [44].

Nevertheless, internationalization in emerging-market firms faces institutional constraints within the global–local business system [45]. On the one hand, excessive government intervention may distort innovation incentives within the domestic business system [46]. On the other hand, political connections can serve as a resource advantage within the institutional business system [47]. Studies on China suggest that state-owned enterprises perform well in innovation transformation, but their internationalization is constrained by governance issues within their business systems [30]. In the current era of global value chain disruption, cross-border knowledge transfer and reverse innovation have become key drivers for technological breakthroughs of emerging market multinational firms [48,49].

2.4. Summary

Overall, traditional institutional economics, innovation theory, and international business research tend to examine standardization, corporate overseas expansion, and technological innovation in isolation [50]. They largely overlook the systemic interplay of diverse actors and factors within regional manufacturing ecosystems and thus fail to explain the synergistic relationships among these key variables. Existing literature presents three major research gaps.

First, scholars lack a systematic understanding of local standards. Current studies mainly focus on the innovation and internationalization effects of national, industrial, and international standards such as ISO, technical specifications, and environmental regulations. They pay insufficient attention to China's province-level local standards. As a critical bridge connecting national macro policies and firm-level micro practices, local standards are well tailored to regional industrial characteristics and facilitate the formation of regional collaborative innovation networks. Nevertheless, their unique systemic value within regional innovation ecosystems remains underexplored.

Second, the mechanism linking standard proliferation to firm innovation quality remains unclear. Prior studies rarely investigate how the growth of standard stock affects innovation quality, which is typically measured by patent citation intensity. Therefore, they cannot fully explain how standard evolution shapes and improves firms' innovation performance.

Third, existing research adopts a relatively narrow perspective and neglects the moderating role of firms' autonomous internationalization. Most literature emphasizes the trade outcomes driven by the international adoption of formal standards. However, few studies examine whether firms' own international expansion, such as overseas market layout and business outreach, alters the relationship between standard constraints and innovation outputs. The governance effect of manufacturing firms' proactive international activities has long been overlooked.

Against these research deficiencies, this study draws on general systems theory to move beyond the conventional single-factor research paradigm. It integrates local standards, corporate internationalization, and radical innovation into a unified analytical framework of regional business ecosystems. This paper systematically explores the intrinsic relationships and transmission mechanisms among the three variables. The findings modestly complement existing literature and provide additional insights for systematic research on standardization, internationalization, and innovation.

3. Research Hypotheses

3.1. Local Product Standards and Radical Innovation in Manufacturing Business Systems

Different from single theories such as institutional economics or the knowledge-based view that only focus on isolated variables, general systems theory regards the manufacturing business system as an organic whole composed of interconnected subsystems. Local product standards belong to the regional institutional subsystem, firm internationalization is a cross-border strategic subsystem, and radical innovation is the output of the whole system. With this theoretical perspective, we can clarify the interactive logic among the three core variables. Regional institutions reshape the system's operating environment, corporate global strategies introduce external resources into the system, and their joint effect drives systemic innovation. Based on the heterogeneous innovation model proposed by Acemoglu et al. [51], we further distinguish incremental innovation and radical innovation and combine institutional parameters to construct a mathematical model for theoretical deduction.

Local product standards regulate quality requirements, technical rules and production processes for regional featured products. They serve as core institutional elements in regional manufacturing systems. These localized regulations directly guide manufacturers' production arrangements and further reshape firms' innovation tendencies within systemic operational environments. Combined with the heterogeneous innovation model and general system theory developed by previous researchers [1,51], this paper empirically explores the incentive effect of government-led local standards on corporate innovation in the manufacturing industry.

This study begins by constructing a consumer preference function, which contains the discount rate ρ and relative risk aversion coefficient v :

$$U = \int_0^{\infty} e^{-\rho t} \frac{C(t)^{1-v} - 1}{1-v} dt \quad (1)$$

The firm uses labor and a set of intermediate goods to produce the final output. The production of the firm is defined as:

$$Y(t) = \frac{1}{1-\beta} \left(\int_{\Phi} q_j(t)^{\beta} k_j(t)^{1-\beta} dj \right) L^{\beta} \quad (2)$$

where β denotes the elasticity of substitution, Φ represents the set of intermediate goods, $k_j(t)$ and $q_j(t)$ denote the quantity and quality of intermediate good j at time t , and L is the total amount of labor.

Since the costs and returns of each intermediate good are independent, the firm chooses the price and quantity to maximize the profit of each intermediate good. Accordingly, from Equation (2), the inverse demand function of intermediate good j is derived as:

$$p_j = L^{\beta} q_j^{\beta} k_j^{-\beta}, \forall j \in \Phi \quad (3)$$

For each intermediate good j , assume that the firm produces with a constant marginal cost γ . The profit maximization function of the firm is then given by:

$$\pi(q_j) = \max_{k_j \geq 0} \{p_j k_j - \gamma k_j\} \quad (4)$$

Substituting Equation (3) into Equation (4) and solving the first-order condition for profit maximization yields:

$$k_j = [(1-\beta)/\gamma]^{1/\beta} L q_j \quad (5)$$

Therefore, the equilibrium profit from intermediate good j is:

$$\pi(q_j) = \beta[(1 - \beta)/\gamma]^{(1-\beta)\beta} L q_j \quad (6)$$

According to the assumption of relevant scholars, a firm can use a product line j with productivity q_i to produce an intermediate good of quality q_j , which is then used to produce the final consumption good [51]. Hence, the intermediate good j discussed in this paper can be regarded as the firm's product line j . Define a constant $\pi = \beta[(1 - \beta)/\gamma]^{1-\beta/\beta} L$. The profit generated from a product line with productivity q_j is therefore πq_j .

Next, consider the firm's innovation choice. Following the assumption of relevant scholars, each product line represents a technological cluster of the firm, and the productivity q_j of a product line is determined by the knowledge level of that cluster [51]. The knowledge level is defined as the number of incremental improvements n made in that field. Let $v(q_j, n)$ denote the value of a product line with productivity q_i after n incremental improvements. For a firm with m product lines, $\vec{q} = \{q_1, q_2, \dots, q_m\}$, each product line corresponds to a technological cluster with incremental improvements $\vec{n} = \{n_1, n_2, \dots, n_m\}$. The total value of the firm can therefore be expressed as:

$$W(\vec{q}, \vec{n}) = \sum_j^m v(q_j, n) \quad (7)$$

The firm chooses its innovation strategy with the goal of maximizing total value. According to the definition of relevant scholars, innovation can be divided into incremental and radical types [51]. Incremental innovation refers to improvements within an existing technological cluster, which are reflected either in additional small improvements or in the enhancement of productivity in an existing product line. Radical innovation, in contrast, refers to the development of new technologies, represented by the creation of a new technological cluster or the emergence of a new product line j' . In other words, incremental innovation raises the productivity q_i of a given product line, while radical innovation increases the firm's overall technological level q_t at time t .

Specifically, for incremental innovation, let η_n denote the productivity gain generated by innovation. The magnitude of this gain depends both on the current position n reached through multiple incremental improvements and on the firm's overall technological level $\bar{q}_t$ at time t . Clearly, $\bar{q}_t$ can be expressed as:

$$\bar{q}_t = \int_{\Phi} q_{jt} dj \quad (8)$$

A single innovation in a product line increases its productivity from q_i to $q_j + \eta_n$. As the firm continues to conduct incremental innovations within the same technological cluster, the productivity gain from each additional innovation gradually diminishes. In other words, as n becomes larger, η_n decays progressively, that is:

$$q_j + \eta_n = q_j + \eta \bar{q} \alpha^n \quad (9)$$

Here, $\eta > 0, \alpha \in (0, 1)$. This implies that the n -th incremental improvement within the technological cluster of product line j raises its productivity by η_n , but the gain decreases geometrically at the rate α . Accordingly, the value of this product line changes from $v(q, n)$ to $v(q_j + \eta_{n+1}, n + 1)$.

For radical innovation, a new technology corresponds to a new product line j' , whose productivity $q_{j'}$ is given by:

$$q_{j'} = \bar{q}_1 + \eta_0 = \bar{q}_t + \eta \bar{q}_t \quad (10)$$

The subscript 0 in η_0 indicates that no incremental innovation has previously occurred in that technological cluster. Clearly, once a radical innovation takes place, a new technological cluster emerges. The firm will then continue to carry out incremental innovations within this new cluster, which continuously raises $\bar{q}$ and, in turn, improves the firm's overall productivity. Accordingly, radical innovation changes the firm's total value from Equation (7) to $EW(\vec{q} \cup \{q_j\}, (n)\vec{n} \cup \{0\})$.

Clearly, the maximization of a firm's total value depends on the combination of product lines and the productivity of each line. Since the product lines are independent of one another, the problem of maximizing the firm's total value can be simplified to maximizing $v(q_j, n)$. For each product line, the firm faces a choice between incremental innovation and radical innovation. This leads to the following Bellman equation for a product line:

$$rv(q_j, n) - \dot{v}(q_j, n) = \pi q_j + \max \left\{ \begin{array}{l} \xi [v(q_j + \eta_{n+1}, n+1) - v(q_j, n)] \\ \psi Ev(\bar{q}_t) \end{array} \right\} - \tau v(q_j, n) + \psi \kappa Ev(\bar{q}_t) \quad (11)$$

Here, r is the given equilibrium interest rate. The right-hand side of the equation indicates that the firm's value consists of three parts: the net profit πq_j generated by current productivity, the change in value resulting from the firm's innovation choice, and the change in value caused by external shocks. In the innovation choice component, ξ is the exogenously given probability of successfully achieving incremental innovation, while ψ represents external factors that influence radical innovation and its expected value, including the effect of local product standards introduced by the government. The term $\tau v(q_j, n)$ captures the change in value due to external shocks, such as when another firm's innovation replaces the product and reduces its value, with probability τ . The term $\psi \kappa Ev(\bar{q}_t)$ reflects the natural occurrence rate κ , which represents the probability that new technologies emerge and generate corresponding expected value regardless of whether the firm chooses incremental or radical innovation, and this is also affected by ψ .

Assume $v(q_j, n) = Aq_j + \tilde{B}(n)\bar{q}_t$. Using the method of undetermined coefficients to solve Equation (11), we obtain $A = \frac{\pi}{r+\tau}$, $\tilde{B}(n) = \frac{1}{r+\tau-g} \left\{ \psi \kappa [A(1+\eta) + \tilde{B}(0)] + \left\{ \begin{array}{l} \xi [A\eta\alpha^{n+1} + \tilde{B}(n+1) - \tilde{B}(n)] \\ \psi [A(1+\eta) + \tilde{B}(0)] \end{array} \right\} \right\}$.

If the firm chooses incremental innovation, then $\tilde{B}(n)$ simplifies to:

$$\tilde{B}(n) = \beta \chi / \xi + \beta A \eta \alpha^{n+1} + \beta \tilde{B}(n+1) \quad (12)$$

If the firm chooses radical innovation, then $\tilde{B}(n)$ simplifies to:

$$\tilde{B}(n) = \frac{\chi + \psi [A(1+\eta) + \tilde{B}(0)]}{r + \tau - g} \quad (13)$$

Here, $\beta = \frac{\xi}{r+\tau-g+\xi}$, $\chi = \frac{\psi \kappa [A(1+\eta) + \tilde{B}(0)]}{r+\tau-g}$ and g denote the steady-state growth rate.

For Equation (12), when n becomes sufficiently large, $\tilde{B}(n)$ converges to $\frac{\chi}{r+\tau-g}$. At this point, the value of $\tilde{B}(n)$ in Equation (12) is clearly smaller than that in Equation (13).

This implies that there must exist a smallest positive integer n^* such that the following condition always holds:

$$\zeta \left[A\eta\alpha^{*+1} + \tilde{B}(n^* + 1) - \tilde{B}(n^*) \right] < \psi \left[A(1 + \eta) + \tilde{B}(0) \right] \quad (14)$$

In other words, n^* represents the technological threshold for a firm to undertake radical innovation. Once n exceeds n^* , choosing radical innovation always leads to value maximization. Therefore, given n^* , we finally obtain:

$$\tilde{B}(n) = \begin{cases} \beta\chi/\zeta + \beta A\eta\alpha^{n+1} + \beta\tilde{B}(n+1), & n < n^* \\ \frac{\chi + \psi \left[A(1 + \eta) + \tilde{B}(0) \right]}{r + \tau - g}, & n \geq n^* \end{cases} \quad (15)$$

Equation (15) confirms that local product standards positively affect radical innovation in manufacturing firms. A higher institutional parameter ψ reduces the critical innovation threshold n^* and lowers technical barriers for radical innovation. This result aligns with core institutional economics arguments. Regional institutional governance mitigates innovation constraints for emerging market firms and echoes mainstream findings in existing institutional research.

In our theoretical framework, ψ is the core institutional parameter capturing the regulatory influence of local product standards on firms' radical innovation choices. An increase in ψ reduces the critical innovation cutoff n^* and elevates the expected payoff of radical innovation, $\tilde{B}(n)$. From an institutional supply perspective, a greater volume of newly released provincial local product standards enhances regional industrial specification systems, strengthens cross-firm knowledge spillovers, and regulates market competition, all of which jointly increase the value of ψ .

To formally link the theory with our empirical strategy, we establish a monotonic increasing functional relationship between the quantity of local product standards and ψ : $\psi_{pt} = \alpha \cdot \ln(\text{Product_sd}_{pt} + 1)$ ($\alpha > 0$). Here, Product_sd_{pt} denotes the count of local product standards issued in province p in year t , which directly corresponds to the core explanatory variable in our subsequent econometric regressions. Adding 1 and taking the natural logarithm addresses zero values and corrects for right-skewness, a practice fully consistent with our empirical measurement approach. This study identifies three core mechanisms that explain how local product standards shape institutional parameters, namely knowledge spillover, fair competition, and market integration.

First, the knowledge spillover mechanism. Local product standards codify scattered, tacit technical knowledge into unified, publicly accessible industrial rules, thereby forming a systematic regional knowledge system. Each newly released standard acts as an effective knowledge diffusion channel within regional innovation ecosystems. It enables firms to better acquire external technical information and accordingly raises the knowledge spillover sub-parameter $\psi_{\text{knowledge}}$.

Second, the fair competition mechanism. The proliferation of local product standards improves the completeness and enforceability of regional market rules. Sound standard systems regulate the production and operational activities of manufacturers, reduce market information asymmetry and opportunistic behavior, and streamline market order. Such institutional improvements optimize the competitive environment, stabilize firms' operational expectations, and enable firms to capture innovation-driven excess returns, which increases the fair competition sub-parameter $\psi_{\text{competition}}$.

Third, the market integration mechanism. Local product standards unify technical specifications and product quality requirements across regions. They eliminate inter-

provincial technical barriers and trade frictions, facilitate cross-regional industrial collaboration, and foster the development of a unified national market. The expanded market scale enlarges firms' innovation profit margins and substantially increases the expected returns of radical innovation, which ultimately enhances the market integration sub-parameter ψ_{market} .

In summary, an increase in the quantity of local product standards raises the overall institutional parameter ψ by simultaneously enhancing these three sub-parameters. This, in turn, lowers the technological threshold n^* for firms' radical innovation and increases its expected return $\tilde{B}(n)$, ultimately promoting radical innovation in manufacturing firms. Based on this, we propose the following testable hypothesis:

H1. *Locally issued product standards positively affect radical innovation among manufacturing firms.*

3.2. Knowledge Spillover Effect

The driving effect of local product standards on firm innovation within the business system is first reflected in their ability to reduce information asymmetry and stimulate knowledge spillovers, thereby providing a micro-level foundation for innovation. Information asymmetry is a key obstacle to knowledge diffusion and technological collaboration among firms within the regional business system [25]. As regional technical rules, local product standards define product parameters, quality criteria and testing methods. They turn tacit technical knowledge into explicit information and greatly mitigate information asymmetry.

Standardized rules greatly reduce firms' cost of obtaining information and speed up knowledge flow in regional ecosystems. In the standardization process, scattered technical experience and research results are integrated into a shared industrial consensus, which realizes effective knowledge integration guided by institutional rules [24]. This forms a formal channel for intra-industry knowledge spillover. Enabled by such knowledge dissemination, manufacturing firms can leverage existing technological achievements to carry out R&D activities. This approach eliminates redundant research trials and lowers experimental costs, encouraging enterprises to invest more resources in technological exploration and ultimately boosting radical innovation performance [51].

Unlike nationwide or international standards, local product standards possess unique region-specific adaptability that closely fits the technological conditions and industrial structures of regional manufacturing systems. Such localized characteristics enable enterprises to absorb coded standard knowledge more effortlessly and convert external information into internal innovative outcomes. Furthermore, government-formulated local standards unify technical specifications for regional upstream and downstream manufacturers, establishing clear reference benchmarks for patent citation activities within innovation systems. These standardized criteria assist enterprises in retrieving relevant patent resources, while built-in compatibility clauses compel firms to incorporate existing patented technologies into their R&D design to avoid technical incompatibility risks.

These optimization effects objectively enhance both the quantity and quality of patent citations across business systems [27]. Standardized technical rules build stable knowledge-sharing networks within regional innovation ecosystems [4]. On this basis, the corresponding research hypothesis is presented below:

H2. *Local product standards boost regional knowledge spillovers, which in turn enhance firms' radical innovation.*

3.3. Fair Competition Effect

Beyond knowledge spillover mechanisms, local product standards can also facilitate radical innovation from a regional institutional perspective. These localized regulations help build a level-playing competitive atmosphere and optimize the institutional environment of business systems, thereby generating long-term innovation incentives for manufacturing enterprises. Fair market competition has long been regarded as a powerful driver that stimulates innovative activities within market ecosystems [52]. As regional institutional rules, local product standards regulate market transactions and restrict corporate opportunistic behaviors. This institutional governance effectively avoids the market failure that low-quality products squeeze out high-quality ones. Consequently, enterprises are forced to prioritize technological upgrading instead of pursuing short-term cost arbitrage to maintain market competitiveness.

The formation of a fair, competitive market is attributed to the unified market rules formulated by local standards. Without standardized industrial criteria, individual firms may take advantage of asymmetric quality information by cutting production requirements to obtain temporary cost edges. This low-price and low-quality competitive pattern diverts corporate resources from long-term technological research toward speculative arbitrage activities, which impairs the sustainable development of business systems [16]. On the contrary, local product standards enhance the transparency of product quality information and mitigate adverse selection problems in the market. Meanwhile, standardized certification and inspection mechanisms raise industrial entry barriers, phasing out unqualified enterprises and restraining unreasonable non-innovative competition within regional markets.

Within a regulated institutional environment, new technologies and processes are more easily rewarded through product premiums and expanded market share, creating positive feedback for innovation within the business system [29]. The implementation of local product standards also requires supporting institutions, such as third-party testing and certification agencies, as well as legal mechanisms, including supervisory regulations and penalties for violations. These measures improve the institutional environment of the business system: legal protections reduce the risk of intellectual property infringement, while market intermediaries facilitate the commercialization of innovation outcomes. Together, they encourage firms to bear the uncertainty of R&D within the business system. Well-designed local standards optimize institutional governance and stimulate long-term exploratory innovation [53]. Based on this, we propose the following hypothesis:

H3. *Local product standards improve regional market competition and facilitate firms' radical innovation.*

3.4. Market Integration Effect

At the regional level, local product standards also promote radical innovation by reducing inter-provincial barriers and facilitating market integration within the broader manufacturing business system. Different technical rules and market access requirements across provinces lead to market segmentation. It hinders scale expansion and efficient resource allocation in national manufacturing sectors and restricts industrial innovation [54]. As a regional coordination tool, local product standards unify technical requirements, foster market integration, and create favorable conditions for a virtuous cycle of large markets and large-scale R&D within the business system.

Market integration essentially weakens interprovincial trade frictions across the nationwide manufacturing business system. In China's institutional context, provincial governments frequently adopt protectionist strategies through differentiated technical

rules. Such discriminatory standard settings restrict the entry of out-of-province goods and ultimately result in fragmented domestic markets [55]. The refinement of local standards serves as an effective solution to mitigate such segmentation issues. For one thing, regional standard convergence decreases technical compatibility expenses and facilitates the cross-regional flow of commodities. For another, the impartial enforcement of local product standards eliminates administrative preference for specific enterprises or technologies, which further diminishes invisible trade obstacles [32].

Market integration exerts innovation-promoting effects through two systematic mechanisms: enlarged market coverage and optimized factor allocation. In terms of market scale, consolidated regional markets expand firms' operational boundaries and potential consumption space. Broader product circulation driven by standardized rules increases the profitability of R&D activities, motivating manufacturers to sustain higher innovation investment. In terms of resource allocation, market integration enables the smoother cross-regional mobility of essential production factors, including professional technicians, testing apparatuses, and manufacturing machinery. Furthermore, unified standard frameworks accelerate the industrialization of scientific achievements, since standardized specifications enhance the applicability of academic and technological outputs for manufacturing enterprises [54]. Standard convergence and market integration help firms cope with global supply chain restructuring [48,56]. Accordingly, this study formulates the research hypothesis below:

H4. *Local product standards advance cross-regional market integration and drive radical innovation in manufacturing firms.*

3.5. The Moderating Role of Firm Internationalization in the Business System

Firm internationalization acts as a critical moderating factor that amplifies the positive correlation between local product standards and corporate innovation in manufacturing business systems. From the perspective of system theory, the internationalization behavior of enterprises connects localized business systems with global industrial ecosystems, enabling the effective combination of regional institutional resources and international market advantages [41]. Existing academic research generally divides firm internationalization into two core dimensions: internationalization depth and breadth [57]. Specifically, internationalization breadth reflects enterprises' overseas market expansion decisions based on external conditions and comparative strengths, whereas internationalization depth measures their participation intensity in single foreign markets [58].

Drawing on the knowledge-based view, internationalization depth enhances firms' absorptive capacity and facilitates the internalization of external technical knowledge embedded in local standards. In accordance with resource dependence theory, internationalization breadth diversifies firms' resource acquisition channels and alleviates institutional lock-in caused by regional institutional constraints. These dual theoretical mechanisms elaborate the intrinsic logical underpinnings of how internationalization reinforces the driving effect of local standards on firms' radical innovation.

Specifically, internationalization enables the in-depth integration of local institutional dividends and global innovation resources and amplifies the innovation-enabling effects of local standards through differentiated pathways [5,49]. Internationalization depth primarily improves firms' internal knowledge absorption capacity to support technology implementation and targeted R&D activities. Firms with high internationalization depth possess extensive experience in advanced technology adoption, R&D management and cross-border operations. They are well aware of the differences and compatibility between local and international standards, which allows them to effectively decode and convert regional technical information embedded in local standards into tangible inno-

vation outcomes [30]. Meanwhile, greater internationalization depth helps firms target overseas market demands and optimize their R&D arrangements. This forms a dual innovation model that balances local institutional adaptation and international compatibility, further stimulating firms' incentives to pursue radical technological breakthroughs.

By contrast, internationalization breadth emphasizes diversified overseas market expansion. It enables firms to acquire heterogeneous technologies and innovation resources from multiple host countries, break through local knowledge boundaries, expand the spillover scope of standard-related knowledge, and mitigate resource constraints imposed by regional institutions. Internationalization breadth and depth function through distinct yet complementary moderating mechanisms, jointly strengthening the positive impact of local standards on radical innovation [30].

In essence, local standards address the regional adaptation problem of innovation within the local business system, while internationalization alleviates resource and market constraints by connecting to the global ecosystem. Their combination creates complementarity between local advantages and global resources, enabling firms to root innovation in local industrial foundations while connecting with global advanced factors within a unified business system. This synergy significantly increases the likelihood of radical innovation. Based on this, we propose the following hypothesis:

H5. *Firm internationalization reinforces the positive link between local product standards and manufacturing firms' radical innovation.*

4. Research Design

4.1. Model Specification and Variable Selection

To examine the impact of local product standards introduced by governments on innovation in manufacturing firms within the business system, the following baseline regression model is specified:

$$Innovation_{i,t} = \alpha_0 + \alpha_1 Product_sd_{i,t} + \sum \alpha_2 X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (16)$$

Radical innovation refers to exploratory technological breakthroughs that break existing technological trajectories. It differs fundamentally from incremental technological improvements [51]. We adopt the invention patent count and patent citation volume as two proxy indicators for three well-grounded reasons.

First, utility model patents mainly represent incremental technical improvements, while invention patents correspond to exploratory R&D activities that develop new technological clusters, which are the most direct output of radical innovation in empirical research on emerging economies [59]. Second, patent citations serve as a globally recognized core indicator for evaluating the novelty and fundamental value of patented technologies, which is highly suitable for measuring radical innovation. Highly cited patents break existing technological paradigms and provide foundational references for subsequent industrial R&D, representing the typical characteristics of radical innovation. In contrast, incremental patents only optimize existing technologies marginally with limited industrial influence and fewer citations, and thus cannot reflect the nature of radical innovation [21]. Third, this two-dimensional measurement framework has been widely adopted in top empirical studies on radical innovation targeting Chinese manufacturing firms. Although no single indicator can fully capture the connotation of radical innovation, the combination of quantity and quality effectively reduces measurement bias caused by a single proxy, which has been fully verified in existing literature [20].

Specifically, $Patent_{i,t}$ is defined as the natural logarithm of the number of invention patent applications adjusted by the IHS transformation, while $Citation_{i,t}$ is the natural

logarithm of cumulative invention patent citations, also adjusted by the IHS transformation. Subscripts i and t denote firm and year, respectively.

The core explanatory variable $\text{Product_sd}_{i,t}$ is defined as the natural logarithm of the number of manufacturing local product standards issued in the province where firm i is located in year t plus 1. This study selects standard quantity instead of alternative indicators, including standard stringency and coverage. Standard quantity offers a direct and objective measure of local institutional supply intensity. It is positively associated with the effectiveness of the three influencing mechanisms. More local standards support sounder technical specifications, more comprehensive market rules, and more consistent cross-regional technical requirements.

X_{it} is a set of firm-level and region-level control variables. Specifically, $\text{Size}_{i,t}$ is the natural logarithm of total assets; $\text{Age}_{i,t}$ is the natural logarithm of the number of years since the firm's listing year plus 1; $\text{Lev}_{i,t}$ is the ratio of total liabilities to total assets; $\text{Capex}_{i,t}$ is the ratio of capital expenditure to total assets; $\text{Agdp}_{i,t}$ is the natural logarithm of the regional per capita GDP (yuan) plus 1; and $\text{Pop}_{i,t}$ is the natural logarithm of the regional population plus 1. μ_i denotes firm fixed effects, γ_t denotes year fixed effects, and ε_{it} is the error term.

4.2. Data Sources and Sample Description

For a long time, based on government issuance and implementation, local standards were divided into two categories: mandatory and recommended. According to the new Standardization Law, effective 1 January 2018, all local standards were unified as recommended standards, with no mandatory enforcement. In other words, since 2018, the binding effect of local governments at the standards level has been relatively weakened. We thus select sample data from 2005 to 2017. In this period, all local product standards were released at provincial or municipal levels, with no prefecture-level standards.

Basic information and financial characteristics of manufacturing firms are obtained from the CSMAR and Wind databases. To ensure the validity of the sample, the following criteria are applied: (1) firms under abnormal operation status, such as ST, *ST, or PT, are excluded; (2) firms listed for less than one year, delisted, or suspended from trading are excluded; (3) firms that issue both B-shares or H-shares are excluded; (4) firms registered outside mainland China are excluded; (5) firms whose annual reports do not clearly disclose overseas business income or whose financial data contain significant omissions are excluded.

After applying these filters, the final sample consists of 1923 firms with 16,423 firm-year observations. Descriptive statistics of the variables used in the baseline regression are presented in Table 1.

Table 1. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Patent	16,423	1.8521	1.5806	0	5.9558
Citation	16,423	1.2965	1.3032	0	4.9706
Product_sd	16,423	2.1959	1.7516	0	5.4889
Size	16,423	21.7803	1.1554	19.1281	25.7803
Age	16,423	1.9349	0.8684	0	3.2189
Lev	16,423	0.4169	0.2056	0.0510	1.1284
Capex	16,423	0.0575	0.0507	0.0001	0.2529
Agdp	16,423	10.7551	0.5896	8.8416	11.7675
Pop	16,423	17.7719	0.6271	15.6123	18.5312

5. Empirical Study

5.1. Core Empirical Findings

Table 2 reports the regression results of the impact of local product standards on breakthrough innovation in local manufacturing firms. Specifically, Columns (1) and (3) present results that include only firm and year fixed effects, with standard errors clustered at the firm level, but without firm-level and provincial-level control variables. The results show a significant positive correlation between local product standards and both invention patent applications and invention patent citations, which supports Hypothesis 1. Columns (2) and (4) add firm-level and provincial-level control variables to the baseline specification. The findings remain consistent, confirming that local product standards promote breakthrough innovation in local manufacturing firms within the business system.

Table 2. Baseline Regression Results.

Variable	(1) Patent	(2) Patent	(3) Citation	(4) Citation
Product_sd	0.082 *** (0.024)	0.066 *** (0.023)	0.064 *** (0.021)	0.047 ** (0.019)
Size		0.504 *** (0.034)		0.374 *** (0.028)
Age		0.115 *** (0.036)		0.073 ** (0.031)
Lev		−0.034 (0.113)		−0.110 (0.096)
Capex		0.314 (0.228)		0.183 (0.199)
Agdp		0.203 (0.211)		0.220 (0.173)
Pop		−0.355 (0.582)		−0.629 (0.483)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	16,423	16,423
Adj. R ²	0.684	0.704	0.654	0.670

Note: Robust standard errors clustered at the firm level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

5.2. Addressing Endogeneity

To address the potential endogeneity between local product standards and corporate radical innovation, this study adopts two instrumental variables (IVs) for cross-validation. The first IV is the share of the secondary industry (Stru). Regions with a higher secondary industry share feature more advanced manufacturing sectors and stronger demand for unified technical specifications, which promotes the formulation and issuance of local product standards. The second IV is the ratio of industrial value added to regional GDP (SecAdd), which measures the provincial level of industrialization. Higher industrialization corresponds to a more sophisticated industrial system and greater demand for standardized production rules, making this indicator highly correlated with the number of local product standards.

In terms of the relevance condition, both indicators are strongly correlated with local product standards. On the one hand, a higher secondary industry share indicates a more prominent manufacturing agglomeration and a stronger positioning as a regional manufacturing hub. A mature local industrial system and supply chain compel local governments to formulate unified and refined product technical standards to adapt to large-scale and

standardized manufacturing development. Meanwhile, regions with a larger secondary industry possess a solid manufacturing foundation, abundant firm resources, and sufficient technical talent. These advantages provide comprehensive technical support, industrial experience, and administrative resources for the formulation, promotion, supervision, and implementation of local standards.

On the other hand, a higher ratio of industrial value added to GDP reflects a higher level of regional industrialization and more scalable and intensive industrial development. A complete industrial system and sophisticated supporting chains drive local governments to establish standardized and detailed product regimes to support high-quality and standardized industrial upgrading. In addition, highly industrialized regions accommodate large industrial output, concentrated manufacturing firms, mature industrial technologies, and abundant professional talents. Such conditions offer solid industrial foundations, professional technical reserves, and sufficient administrative support for the revision, promotion, supervision, and enforcement of local product standards, thereby facilitating the continuous formulation and iteration of local standards and ensuring the validity of IV relevance.

In terms of the exogeneity condition, both the secondary industry share and the industrial value-added ratio are macro-level regional industrial characteristics. They only reflect the overall scale and development status of regional industries and do not directly interfere with firms' micro-level R&D and innovation decisions. These two indicators affect corporate radical innovation solely through a single policy channel: the formulation and implementation of local product standards, which satisfy the core exogeneity requirement for instrumental variables. This study defines the secondary industry share as the ratio of provincial secondary industry value added to the total value added of the primary, secondary, and tertiary industries to ensure standardized and consistent measurement.

Table 3 presents the estimation results of the two-stage least squares (2SLS) approach. The first-stage regression results show that both Stru and SecAdd exert significant positive effects on the number of local product standards ($Product_sd$) at the 1% statistical level. The corresponding first-stage F-statistics are 41.02 and 42.69, respectively, which are far above the critical value of 10 and rule out the weak instrument problem. The significant Kleibergen-Paap rk LM and Wald F statistics further confirm that the model passes the under-identification test. The second-stage results indicate that local product standards yield significantly positive coefficients at the 1% level when radical innovation is measured by patent quantity and patent citations. These findings further verify the positive impact of local product standards on corporate radical innovation.

Table 3. IV Estimation.

	(1)	(2)	(3)	(4)	(5)	(6)
	Product_sd First-Stage	Patent Second-Stage	Citation Second-Stage	Product_sd First-Stage	Patent Second-Stage	Citation Second-Stage
Stru	7.869 *** (0.609)					
SecAdd				8.044 *** (0.620)		
Product_sd		0.348 *** (0.104)	0.266 *** (0.082)		0.384 *** (0.102)	0.277 *** (0.082)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16,423	16,423	16,423	16,423	16,423	16,423
The first-stage F statistic	41.02			42.69		
Kleibergen-Paap rk LM statistic		105.160			107.317	
Kleibergen-Paap rk Wald F statistic		166.906			168.621	

Note: Robust standard errors clustered at the firm level are reported in parentheses. *** $p < 0.01$.

5.3. Robustness Tests

Local standards can be classified into multiple categories depending on the objects of standardization, including local product standards, local management standards, local environmental standards, and local safety standards. Considering that types of local standards other than product standards may also influence firms' production activities within the business system, this study replaces the explanatory variable with the total number of all local standards to conduct robustness tests. The regression results are reported in Table 4. It can be seen that the corresponding coefficients remain significantly positive, thereby confirming the robustness of the baseline regression results.

Table 4. Robustness Test: Replacing the Explanatory Variable (with All Local Standards).

Variable	(1) Patent	(2) Patent	(3) Citation	(4) Citation
All_sd	0.083 *** (0.025)	0.075 *** (0.024)	0.040 * (0.021)	0.041 ** (0.021)
Constant	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	16,423	16,423
Adj. R ²	0.683	0.704	0.653	0.670

Note: Robust standard errors clustered at the firm level are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In addition, considering that the sample may suffer from a severe left-skewed distribution and that the minimum value of the dependent variable is zero, we re-estimate the model using a fixed-effects Tobit model and a high-dimensional fixed-effects panel Poisson pseudo-maximum likelihood estimator. The regression results are reported in Table 5. To address potential measurement errors caused by extreme values, we conduct robustness checks by winsorizing the sample at the 1% level on both tails and by excluding data related to the 2008 financial crisis, with the results presented in Table 6.

Table 5. Robustness Test: Alternative Estimation Methods.

Variable	(1)	(2)	(3)	(4)
	Patent Xttobit	Citation	Patent Ppmlhdfe	Citation
Product_sd	0.009 * (0.005)	0.009 * (0.005)	0.028 * (0.016)	0.032 * (0.018)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	15,677	15,677
Pseudo R ²	/	/	0.262	0.275

Note: Robust standard errors clustered at the firm level are reported in parentheses. * $p < 0.1$.

Finally, to mitigate potential omitted variable bias, we perform robustness tests by controlling for city-level fixed effects and clustering the standard errors at the city level, with the results shown in Table 7. As can be observed, the regression coefficients of the corresponding variables in Tables 5–7 remain significantly positive, further confirming the robustness of the baseline results within the business system context.

Table 6. Robustness Test: Excluding Extreme Values.

Variable	(1)	(2)	(3)	(4)
	Winsorized 1% Patent	Citation	Excluding 2008 Crisis Patent	Crisis Citation
Product_sd	0.067 *** (0.023)	0.048 ** (0.019)	0.059 ** (0.023)	0.043 ** (0.019)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	15,596	15,596
Adj. R ²	0.704	0.670	0.707	0.673

Note: Robust standard errors clustered at the firm level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Table 7. Robustness Test: Controlling for City-Level Omitted Variables.

Variable	(1)	(2)	(3)	(4)
	City FE Patent	Citation	Clustered at City Level Patent	Citation
Product_sd	0.066 *** (0.023)	0.047 ** (0.020)	0.066 ** (0.027)	0.047 ** (0.022)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	16,423	16,423
Adj. R ²	0.697	0.662	0.704	0.670

Note: Robust standard errors clustered at the firm level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

We conduct an additional robustness test by replacing the core explanatory variable with the annual newly issued local product standard quantity. The benchmark regression results stay significantly positive, further corroborating that rising standard quantity increases the theoretical parameter ψ and spurs corporate radical innovation, which strengthens the consistency between theoretical deduction and empirical estimation.

6. Mechanism Analysis and Heterogeneity Tests

6.1. Transmission Mechanisms

To explore the three systemic mechanisms linking local product standards to manufacturers' radical innovation, this study adopts a stepwise approach for mechanism verification. It empirically unpacks how local product standards function within manufacturing business systems by examining knowledge spillover, fair competition and market integration, respectively.

This section focuses on the three systemic mechanisms through which local product standards influence firms' radical innovation within the manufacturing business system. For the knowledge spillover effect that facilitates technology diffusion within the system, we use the number of patents cited by invention patents to measure it. This indicator reflects the extent to which firms absorb and utilize external knowledge in the innovation process within their business systems. A higher number of citations indicates more active knowledge flows across firms. Column (1) of Table 8 reports the results, which confirm Hypothesis 2.

Table 8. Mechanism Tests.

Variable	(1) Fcitation	(2) Law	(3) Minteg
Product_sd	0.086 *** (0.032)	0.179 *** (0.024)	0.037 *** (0.002)
Constant	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	16,423	16,423	16,423
Adj. R ²	0.671	0.923	0.752

Note: Robust standard errors clustered at the firm level are reported in parentheses. *** $p < 0.01$.

For the fair competition effect that improves institutional conditions within the business system, we employ the development of market intermediaries and the legal environment as measures. The data are drawn from the Marketization Index calculated by Fan Gang and colleagues, which quantifies institutional quality from two perspectives: the development of market intermediaries and the protection of property rights by law. A higher score indicates more regulated market competition and stronger protection of innovation outcomes within the business system. Column (2) of Table 8 shows that local product standards significantly improve radical innovation through the fair competition effect, confirming Hypothesis 3.

For the market integration effect that reduces inter-provincial barriers within the national manufacturing system, we use the market integration index calculated by the price method. This indicator reflects the degree of market segmentation by measuring the synchronicity of product price fluctuations across regions. A higher value indicates weaker provincial barriers and stronger market integration within the business system. Column (3) of Table 8 confirms Hypothesis 4.

It should be noted that the stepwise testing method adopted in this study clearly identifies core transmission paths, yet has certain limitations. This method cannot accurately estimate the contribution of each path. Nor can it fully rule out disturbances from other potential factors in the transmission process. Given the research objectives and data characteristics, this study mainly focuses on verifying the validity of relevant mechanisms. Regression results based on three types of proxy variables solidly prove that local product standards affect radical innovation in manufacturing firms jointly through knowledge spillover, fair competition and market integration.

6.2. Moderation Analysis of Internationalization

Scholars have developed a systematic measurement framework for internationalization indicators, evolving from single-dimensional to composite multi-dimensional metrics. Existing literature recognizes that internationalization is a multi-faceted concept consisting of breadth, depth and speed, rather than a single construct. Zhang et al. (2023) define internationalization breadth as the geographic scope of multinational firms' overseas operations [60]. Liu et al. (2024) adopt the most classic and reliable single indicator in international business research to measure internationalization depth, namely the ratio of overseas sales revenue to total sales revenue [61]. Xiong et al. (2024) describe internationalization speed as the average annual change rate of this ratio over a given period [62]. To accurately identify the moderating effect of corporate internationalization strategies, this study divides internationalization into two dimensions, namely breadth and depth. Internationalization breadth is measured by the number of countries and regions hosting a firm's overseas subsidiaries. It reflects the geographic diversification of a firm's global

footprint. Internationalization depth is captured by the ratio of overseas operating income to total operating income. This continuous variable ranges from zero to one. It objectively reflects a firm's reliance on overseas markets and its capacity to integrate global resources.

The regression results in Table 9 support Hypothesis H5. They also reveal that internationalization breadth and depth exert moderating effects through distinct channels. Internationalization breadth generates a significant positive moderating effect. Firms with subsidiaries across more regions gain access to diverse technologies and market information. This extends the scope of knowledge spillovers driven by local product standards. The coefficient of the interaction term between local product standards and internationalization breadth stands at 0.012 for patent applications and 0.009 for patent citations. Both results are statistically significant at the one percent level. These firms integrate technological trends from various economies to develop innovative products with stronger global competitiveness. They therefore strengthen the positive influence of local product standards on radical innovation.

Table 9. Moderating Effect of Internationalization.

Variable	(1) Patent	(2) Citation	(3) Patent	(4) Citation
Product_sd	0.054 ** (0.023)	0.038 * (0.020)	0.057 ** (0.024)	0.040 ** (0.020)
Product_sd × Wide	0.012 *** (0.004)	0.009 *** (0.003)		
Product_sd × Deep			0.068 ** (0.034)	0.054 * (0.029)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,423	16,423	16,423	16,423
Adj. R ²	0.697	0.663	0.697	0.662

Note: Robust standard errors clustered at the firm level are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results presented in Columns 3 and 4 confirm the significant positive moderating effect of internationalization depth. Firms with greater reliance on overseas markets demonstrate stronger capabilities to absorb and apply technical knowledge embedded in local product standards. The interaction term yields a coefficient of 0.068 for patent applications and 0.054 for patent citations. The two figures are significant at the five percent level and the ten percent level, respectively. Firms with deep international engagement constantly adjust products and technologies to meet diverse demands across global markets. This motivates them to leverage technical specifications and market rules set by local product standards in their innovation activities.

6.3. Heterogeneity Analysis

6.3.1. Digital Transformation

Digital transformation captures a firm's ability to process information, integrate knowledge and coordinate business activities using digital technologies. Drawing on prior studies, we measure digital transformation through text analysis of relevant keywords. Firms scoring above the sample mean are assigned a value of 1, and all others 0 [24].

Table 10 shows that local product standards significantly promote radical innovation at firms with low digital transformation. No such effect exists for highly digitalized firms. A bootstrap test with 1000 replications confirms a statistically significant difference

between the two groups. Firms with robust digital capabilities handle information and share knowledge efficiently, so they rely little on knowledge spillovers from standards. Firms with weak digital foundations face higher costs to obtain information. Local product standards streamline knowledge exchange within the industry and deliver stronger gains for their radical innovation.

Table 10. Heterogeneity Analysis: Firms' Digital Transformation.

Variable	(1) Digit1 = 1 Patent	(2) Digit1 = 0 Patent	(3) Digit1 = 1 Citation	(4) Digit1 = 0 Citation
Product_sd	−0.028 (0.046)	0.074 *** (0.028)	−0.012 (0.042)	0.053 ** (0.023)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	7370	9053	7370	9053
Adj. R ²	0.753	0.641	0.727	0.618
Group-diff Test	0.102 *** [0.002]		0.065 *** [0.006]	

Note: Robust standard errors clustered at the firm level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Digital innovation and business performance change alongside firm development and external circumstances [63]. In emerging economies, firms at an early digital stage lack proprietary technology and mature digital skills. Their digital progress depends heavily on external institutions [64]. Such firms use institutional resources including local product standards to address internal limitations and advance radical innovation. Firms with low digital transformation remain in the early development phase. They face notable structural constraints and limited in-house technology and tend to build innovation frameworks around formal industrial rules such as local standards [63]. This developmental perspective explains the mechanisms driving heterogeneous innovation responses to local product standards.

6.3.2. Business Credit

Accounts payable represent deferred payments granted by suppliers and indicate the level of business credit a firm enjoys within the supply chain system. A higher share of accounts payable in total assets implies stronger business credit. Following existing research, we measure business credit as the ratio of accounts payable, notes payable, and customer advances to total assets [65]. Firms above the sample mean are coded as Buscre = 1, and others as 0.

Table 11 shows that local product standards significantly promote radical innovation in firms with low business credit, while the effect is not significant for firms with high business credit. The between-group difference is only marginally significant at the 10% level. We thus interpret this heterogeneous pattern with caution. Firms with sound business credit can access ample resources and build trust via supply chain networks, so they rely less on external institutions. By creating a fairer competitive environment within the business system, local product standards reduce transaction risks for low-credit firms, provide them with stable expectations, and thus more strongly promote radical innovation.

Table 11. Heterogeneity Analysis: Firms' Business Credit.

Variable	(1) Buscre1 = 1 Patent	(2) Buscre1 = 0 Patent	(3) Buscre1 = 1 Citation	(4) Buscre1 = 0 Citation
Product_sd	0.033 (0.039)	0.073 *** (0.027)	0.018 (0.033)	0.053 ** (0.023)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6641	9782	6641	9782
Adj. R ²	0.753	0.673	0.720	0.635
Group-diff Test	0.040 * [0.093]		0.035 * [0.097]	

Note: Robust standard errors clustered at the firm level are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6.3.3. Industry Attributes

The difference between high-tech and non-high-tech firms is significant at the 10% level, revealing heterogeneous effects across the sample. Manufacturing subsectors differ in technological intensity, which leads to varied innovation performance among firms. We use a high-tech industry dummy to divide the sample into two groups.

Table 12 shows that local standards generate a stronger impact on non-high-tech firms. One possible explanation is that high-tech firms experience faster technological upgrading and enjoy stronger innovation autonomy within their business systems, making them less reliant on local standards. By contrast, non-high-tech firms depend more on traditional technologies and face greater systemic constraints, so local product standards are more likely to stimulate their radical innovation and industrial upgrading within the business system.

Table 12. Heterogeneity Analysis: Firms' Technology Differences.

Variable	(1) Hightech = 1 Patent	(2) Hightech = 0 Patent	(3) Hightech = 1 Citation	(4) Hightech = 0 Citation
Product_sd	0.051 (0.036)	0.067 ** (0.031)	0.025 (0.032)	0.062 ** (0.026)
Constant	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6677	9746	6677	9746
Adj. R ²	0.722	0.682	0.690	0.654
Group-diff Test	0.016 [0.265]		0.037 * [0.088]	

Note: Robust standard errors clustered at the firm level are reported in parentheses. * $p < 0.1$, ** $p < 0.05$.

Overall, local product standards present an obvious short-board compensation trend when driving radical innovation across manufacturing firms. Its promotional impact is relatively stronger for enterprises with insufficient digital capabilities, poor business credit and weak technological foundations. This finding also delivers valuable implications for local governments to formulate differentiated standard policies and optimize the overall operation of the manufacturing business system.

7. Discussion

Drawing on systems theory, this study examines the relationships between local standards, corporate internationalization and radical innovation within manufacturing business ecosystems. Unlike prior work that isolates these research elements, this paper explains the synergy between local institutional provisions and firms' global expansion.

First, this study builds an integrated analytical framework covering knowledge spillovers, fair competition and market integration. It clarifies how local product standards facilitate radical innovation and verifies that subnational institutional rules act as a key driver of innovation in emerging economies. While most existing literature focuses on national or international standards, this paper targets provincial local standards in China, adding unique micro-level evidence to research on regional institutional innovation. Second, this study divides internationalization into breadth and depth and identifies their distinct moderating mechanisms. Consistent with Shen et al. (2023) [30], it confirms the moderating effect of internationalization on the link between local product standards and radical innovation. This work moves beyond the common single-dimensional research paradigm in emerging market internationalization studies and explains how institutional factors interact with internationalization strategies under the dual-circulation framework. Third, this paper identifies a notable compensatory effect of local standards, which represents a key research innovation. As formal institutions, local product standards make up for resource shortages and systematic weaknesses among manufacturers that lack digital capabilities, business credit or independent technological strengths. This finding aligns with existing theories on institutional governance and extends relevant research from general regulations to local product standards.

This paper reaches conclusions different from several earlier studies on technical standards and innovation. Previous research using European manufacturing data argues that technical standards create path dependence and hinder radical innovation. This study obtains opposite results in the Chinese context. Standards vary greatly in their positioning and operational logic across different institutional settings. European technical standards are market-driven industry consensus. Before 2018, China's local product standards served as policy-oriented institutional tools designed to eliminate regional market segmentation and streamline knowledge flows.

China revised its Standardization Law in 2018. The reform converted local standards from mandatory rules to voluntary guidelines, yet their core functions remain unchanged. Without administrative enforcement, voluntary standards still operate through three main channels. They consolidate scattered tacit technical know-how into public specifications and accelerate regional knowledge spillovers through inter-firm collaboration. They establish unified industrial norms to curb disorderly competition and maintain a fair market environment. They also adopt consistent technical requirements to remove inter-provincial technical trade barriers and advance cross-regional market integration. Our empirical sample spans the period from 2005 to 2017, but the operational logic of local standards still applies to the post-2018 institutional environment. Currently, local standards deliver positive outcomes supported by industry-wide voluntary compliance and industrial chain expectations. The shift from administrative enforcement to market orientation does not alter the fundamental role of local standards as technical specifications and market rules. On the contrary, it strengthens their capacity to boost innovation. The three core mechanisms summarized in this paper remain effective under the voluntary standard system. Therefore, the research findings carry practical implications for current industrial development and standard governance.

8. Conclusions and Implications

This study uses panel data of Chinese listed manufacturing firms from 2005 to 2017 to examine the systemic impacts of local product standards on corporate radical innovation and explore the underlying transmission mechanisms. Empirical results demonstrate that locally formulated product standards exert a positive effect on radical innovation in manufacturing enterprises. This paper establishes an integrated analytical framework covering knowledge spillovers, fair competition and market integration to clarify how local standard systems drive radical innovation. The positive innovation effects of local product standards stem from three interconnected systemic mechanisms. Knowledge spillovers cut R&D trial costs. Fair competition corrects the market failure of bad products, driving out good ones. Market integration expands profit margins for radical innovation. Combined together, these mechanisms substantially lower the innovation barriers for manufacturers. The results also reveal the significant moderating role of corporate internationalization. Internationalization depth enhances firms' capacity to capture institutional dividends, while internationalization breadth extends the reach of knowledge spillovers generated by local standards. This outcome explains the interplay between institutional rules and global expansion strategies within manufacturing business systems under the dual-circulation framework. It also echoes existing studies on institutional governance and further proves that local product standards empower resource-constrained manufacturers.

This research offers clear policy implications for the upgrading of manufacturing sectors. First, regional governments should continuously improve local product standard systems. Well-designed standards reduce innovation barriers, regulate market order and facilitate regional market integration. Governments need to formulate standards tailored to local industrial features to promote knowledge sharing and sustain fair competition across industries. Second, policymakers shall take full account of firm heterogeneity when designing regulatory frameworks. For manufacturers with weak independent innovation capacity, local standards serve as an effective institutional tool. They reduce the costs and risks of radical technological breakthroughs and narrow the innovation gap among different types of enterprises. Third, local standard-setting should be closely integrated with corporate internationalization strategies to leverage complementary strengths. This approach helps manufacturers build solid innovation capabilities based on local industrial endowments and access high-quality global production resources. Amid intensifying global technological competition, this policy direction is vital for Chinese manufacturers to strengthen their international competitiveness.

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