

Article

The “From Point to Area” Effect of Leading Enterprises’ Digital Transformation on Entrepreneurship: Evidence from China’s Lighthouse Factories

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Abstract

The role of externalities generated by enterprise digital transformation in advancing SDGs 8 and 9 has been largely overlooked in existing research. Taking Lighthouse Factory certification (LFC) as a quasi-natural experiment, this paper uses China’s county-level panel data from 2016 to 2023 and adopts the DID model to investigate the impact of leading enterprises’ digital transformation on regional digital entrepreneurship (RDE). The findings show that LFC promotes RDE by facilitating digital technology transfer, deepening digital technology cooperation, accelerating digital knowledge accumulation, and enhancing local digital industrial competitiveness. Moreover, this effect is more pronounced in regions with stricter environmental regulations and a stronger green transformation climate, yet is less constrained by local digital infrastructure. Interestingly, LFC exerts positive spillover effects on surrounding cities within 50–150 km and those beyond 250 km, whereas it exerts a significant siphon effect on cities within 50 km. Furthermore, LFC generates network spillovers among economically connected cities through regional digital technology transfer and cooperation networks. This paper provides empirical evidence for leveraging the demonstration effect of leading enterprises to promote the coordinated implementation of SDG 8, SDG 9, SDG 10, SDG 12 and SDG 13.

Keywords: enterprise digital transformation; digital entrepreneurship; lighthouse factory; leading enterprises; entrepreneurial ecosystem; sustainability

1. Introduction

Currently, global economic growth has entered a downward cycle characterized by weak growth, sluggish recovery, and widening cross-country divergence [1] (pp. 61–78). In April 2026, the International Monetary Fund updated its World Economic Outlook and revised down its global growth projection for 2026 to 3.1%, below the 2000–2019 historical average of 3.7%.

Meanwhile, powered by digital technologies such as artificial intelligence, big data, cloud computing, and the Internet of Things (IoT), the digital economy has reshaped traditional growth models and is seen as a source of sustained momentum for global growth [2]. According to the 2025 Global Digital Intelligence Index (GDII), digital transformation investment has generated steadily increasing economic returns. In 2025, each US dollar invested in global digital transformation generated approximately \$9.55 in economic output.

Against this backdrop, scholars and practitioners have shown growing interest in how to jointly promote SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry,



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Innovation and Infrastructure) by fostering the digital economy. Like many other countries, China has been striving to advance the digital transformation of its manufacturing sector since 2015. To address the lack of practical experience in digital transformation, the Chinese government has introduced a series of relevant policies, among which leveraging the demonstration role of manufacturing benchmark enterprises has become a core direction.

As digital transformation continues to advance, its effect on entrepreneurship has drawn increasing scholarly attention. Digital entrepreneurship can not only drive regional economic growth but also trigger creative destruction, reshape market competition, and advance institutional reform, thus having profound implications for urban sustainable development. Existing literature has explored the drivers of digital entrepreneurship from multiple perspectives, including the application of digital technologies [3], changes in the business environment [4], support from local governments [5], backing from diverse stakeholders [6], and the cultivation of entrepreneurial intentions [7]. However, although policies in some countries increasingly highlight the exemplary role of benchmark enterprises in digital economy development, few studies have explained the rapid rise in digital entrepreneurship from the perspective of cultivating such enterprises.

The concept of benchmark enterprises is theoretically grounded in Chandler's notion of leading enterprises [8,9]. Existing studies present two opposing views on the economic effects of leading enterprises. One view suggests that they play a key role in technological advancement and knowledge diffusion, thereby enhancing overall social welfare [10,11]. The opposing view holds that once leading enterprises have completed their technological upgrade, they tend to expand their market share, which may lead to industry monopolies and even a winner-takes-all market structure, thereby hindering the development of SMEs [12]. Nevertheless, existing studies on leading enterprises predominantly focus on their impact on competing SMEs and firms along the industrial chain. Limited attention has been paid to their effects on local start-ups, as well as their spatial spillover effects on start-ups in other regions.

Focusing on the externalities of digital transformation among manufacturing leading enterprises, this paper treats Lighthouse Factory certification (LFC) as a county-level quasi-natural experiment to examine its impact on regional digital entrepreneurship (RDE). The findings suggest that the digital transformation of leading enterprises improves local conditions for digital entrepreneurship and fosters RDE. In addition, significant spatial spillover effects are observed in adjacent cities and network-connected cities through regional technology transfer and cooperation linkages.

This paper argues that LFC can serve as an indicator of leading enterprises' digital transformation for two reasons. First, the certification process requires applicant firms to demonstrate measurable improvements across multiple key performance indicators, which are direct outcomes of deep digital transformation. Second, certified factories are required to share their successful experiences with other local firms, suggesting that the certification captures not only the internal transformation status of enterprises but also their potential to generate external spillovers. Therefore, although LFC does not fully capture the entire scope of leading enterprises' digital transformation, it reliably identifies firms' efforts to achieve a high level of digital maturity and grow into leading enterprises, as well as their positive externalities on the regional digital entrepreneurship environment.

The contributions of this paper are as follows. First, it identifies the interactions between leading enterprises and start-ups in the context of digital transformation, thereby enriching the literature on digital transformation coordination across firms and extending research on the economic consequences of leading enterprises. Second, it reveals the positive externalities of leading enterprises' digital transformation, thereby supplementing relevant studies on the determinants of entrepreneurship. Enterprise digital

transformation is not only a contextual reality but also a key driver of regional innovation and entrepreneurship—a perspective largely overlooked in previous research on SDG 8 and SDG 9. Third, this paper identifies the spatial spillover effects of enterprise digital transformation, thereby broadening the understanding of its economic consequences and uncovering heterogeneous patterns of spatial spillovers. Existing literature has examined the impacts of digital transformation at individual, organizational, industrial, and regional levels, but has largely neglected cross-level linkages and interactive mechanisms.

The remainder of this paper is structured as follows. Section 2 outlines the policy background of LFC and proposes research hypotheses. Section 3 introduces the empirical research design and data sources. Section 4 empirically examines the impact of LFC on RDE. Section 5 explores the potential mechanisms through which LFC affects RDE. Section 6 further analyzes the spatial spillover effects of LFC. Finally, Sections 7 and 8 summarize the main findings and put forward targeted policy recommendations.

2. Research Background and Hypotheses

2.1. Research Background

Lighthouse Factories, designated by the World Economic Forum in Davos, are exemplary production facilities that represent the world's highest level of digitalization and intelligent manufacturing. The selection criteria span multiple dimensions, including technology, organizational management, and business operations. At the core are the large-scale deployment and in-depth application of intelligent and digital technologies (e.g., AI, IoT, and big data analytics), along with efficient and sustainable production capabilities. The certification data used in this paper cover the first ten batches of Lighthouse Factories released by the WEF from 2018 to 2023. The number of certified Lighthouse Factories located in mainland China over the years and their geographical distribution are shown in Figure 1, respectively.

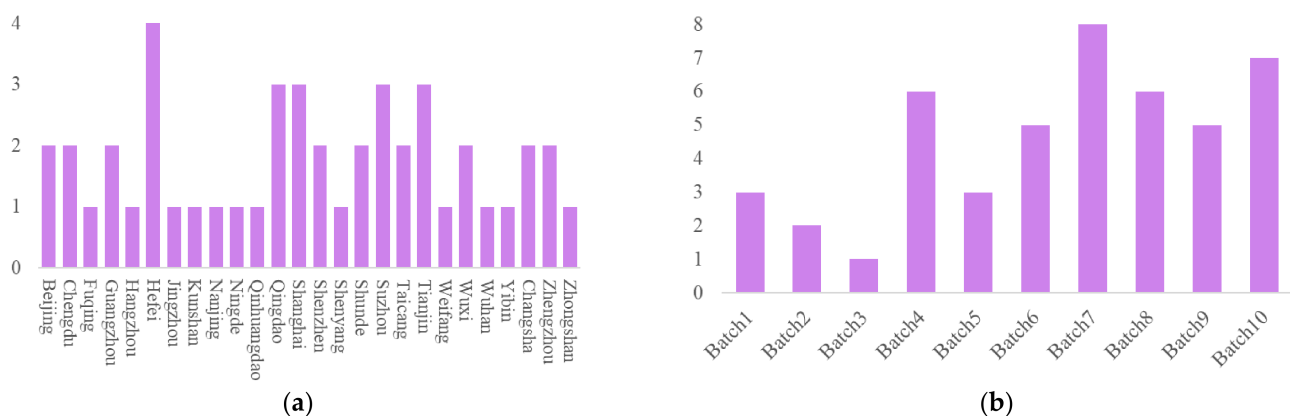


Figure 1. (a) Spatial distribution of lighthouse factories; (b) number of certified firms by batch.

Drawing on relevant literature and the research theme of this paper, this paper summarizes three key contextual features of Lighthouse Factory certification below.

First, Lighthouse Factories have received strong support from various local governments in China. Extant literature suggests that government support is an important factor influencing the effectiveness of voluntary industrial policies [13]. Given that the development of Lighthouse Factories aligns closely with local governments' goals of promoting digital transformation in manufacturing, regional incentive policies for Lighthouse Factory certification are often more generous than those for top-tier national manufacturing certifications. For instance, Quanzhou provides a subsidy of RMB 10 million, Bao'an District of

Shenzhen provides RMB 5 million, Suzhou provides RMB 4 million, and Hefei provides RMB 3 million to support the establishment and development of Lighthouse Factories.

Second, Lighthouse Factories generate demonstration effects that may be stronger than those of the leading enterprises commonly discussed in prior studies. Existing studies indicate that SMEs tend to emulate large enterprises, yet large enterprises' strategic decisions do not always exert a demonstration effect on SMEs, as the enormous R&D investment and sophisticated organizational structures of large enterprises pose substantial barriers to SME imitation [14]. In contrast, a Lighthouse Factory is not a large-scale, fully integrated conglomerate but rather a micro-level production unit. Such unit-level transformation experience features a higher degree of modularity and portability, enabling other manufacturing enterprises to learn and apply digital transformation practices without replicating the complex organizational architecture of entire corporate groups. This significantly lowers imitation barriers and strengthens the demonstration effects of Lighthouse Factories. Furthermore, the demonstration effect of Lighthouse Factories is amplified by local governments, which facilitate the dissemination of best practices through financial subsidies, Lighthouse industry summits, and official white papers.

Finally, the economic impact of Lighthouse Factories may continue to accumulate over time. Enterprises expect to access more high-quality resources and gain competitive advantages by obtaining Lighthouse Factory certification, which motivates them to actively participate in the certification selection process. In turn, once a Lighthouse Factory is established in a region, other uncertified manufacturing enterprises in the same industry will pursue catch-up transformation to compete for policy resources and sustain their market competitiveness [15]. Over time, more enterprises capable of digital transformation will embark on this process, creating a positive multiplier effect.

2.2. Research Hypotheses

During digital transformation, Lighthouse Factories have accomplished technological feasibility evaluation and scenario adaptation, forming mature and replicable digital transformation pathways. Such proven practices may influence the digital transformation behavior of other local enterprises and change the regional digital entrepreneurial environment.

First, the digital transformation of Lighthouse Factories may provide clearer and more targeted entrepreneurial opportunities for digital start-ups. Existing research has confirmed that SMEs tend to imitate the strategic behaviors of large enterprises during their development [14]. Furthermore, after large enterprises reduce production costs and improve production efficiency through digital transformation, laggard firms face continuous market share erosion [16]. Consequently, local manufacturing enterprises may emulate the digital transformation pathways of Lighthouse Factories, transforming individual firms' demand for industrial software, the Industrial Internet of Things, data solutions, and other digital products and services into industry-wide generic demand. The formation of such generic demand not only expands digital entrepreneurial opportunities but also mitigates information asymmetry and reduces the information search costs of start-ups [17].

Second, the digital transformation of Lighthouse Factories can accelerate the accumulation of urban digital technology. As presented in the Lighthouse Factory White Paper, Haier's interconnected refrigerator Lighthouse Factory in Shenyang applied 3D digital twin technology to product development and testing, shortening the new product development cycle by 30%. In the manufacturing phase, the deployment of digital pull systems and workshop automation increased production capacity by 79%. By introducing and developing emerging digital technologies, Lighthouse Factories can drive the digital innovation of other firms through multiple mechanisms, including knowledge spillover, market

competition, and industrial and supply chain spillovers, thereby further accelerating the accumulation of urban digital technology [18,19]. The growth of local digital technology endowment not only opens up new directions for digital entrepreneurship but also lowers the cost of digital technology for digital start-ups and alleviates their capital constraints in the early stage of entrepreneurship.

Third, the digital transformation of Lighthouse Factories may improve the local digital entrepreneurship environment and underpin digital entrepreneurial activities. According to regional entrepreneurship ecosystem theory, the institutional environment and human capital are key determinants of entrepreneurship [20,21]. On the one hand, local governments generally roll out supportive policies—including streamlined administrative approval procedures and public service platforms—to cultivate Lighthouse Factories, and such policy dividends spill over to a broader range of market participants. Accordingly, digital entrepreneurs can benefit from lower institutional transaction costs in qualification applications, project declarations, and other administrative procedures. On the other hand, the digital transformation of manufacturing industries, driven by the demonstration effect of Lighthouse Factories, cultivates a large pool of interdisciplinary digital talent, thereby enriching urban human capital stock and providing solid talent support for local digital entrepreneurship. Based on the above analysis, this paper proposes the following hypotheses:

H1: *LFC promotes RDE.*

Technology transfer refers to the cross-regional inflow and outflow of technologies driven by technological gaps and technological demand [22]. Technological demand serves as the core driver of technology transfer. Lighthouse Factories expand the application scenarios of digital technologies and drive the digital transformation of enterprises within the same industry. This may increase other firms' demand for digital technologies in the city and accelerate the transfer of local and external digital technologies to county-level regions. Fabrizio et al. show that demand–pull policies targeting enterprise technological needs outperform supply–push alternatives that prioritize technology supply in promoting technology transfer [23].

Furthermore, the adoption of external digital technologies by Lighthouse Factories can generate a demonstration effect in digital technology transactions. This improves the efficiency of information matching between digital technology suppliers and demanders and lowers the search costs of digital technologies [24]. Finally, Lighthouse Factories facilitate improvements in supporting systems related to digital transformation, creating a sound institutional environment for other urban enterprises to introduce digital technologies. This reduces friction and transaction costs in the industrialization and commercialization of digital technologies [25].

Existing literature has confirmed that technology transfer significantly facilitates entrepreneurship by expanding entrepreneurial opportunities, reducing the cost of digital technologies, stimulating innovation, and accelerating the flow of other entrepreneurial factors [24,26,27]. Based on the above analysis, this paper proposes the following hypothesis.

H2: *LFC promotes RDE by facilitating digital technology transfer.*

The digital transformation of Lighthouse Factories delivers a demonstration effect on other manufacturing firms, boosts urban market demand for new digital technologies, and promotes technological innovation [28]. Extant literature suggests that the availability of technological and market information is a key determinant of effective technological cooperation [29]. The proven digital transformation experiences of Lighthouse Facto-

ries clarify the correct direction of digital innovation, alleviate information asymmetry in collaborative innovation processes and lower the risks of digital technology collaboration [30]. Furthermore, the digital transformation initiated by Lighthouse Factories may promote the formulation of unified standards for data specifications, interface protocols, and cybersecurity norms, which mitigate compatibility barriers to cross-enterprise technical cooperation [31].

Existing studies have documented that inter-regional technological cooperation contributes positively to entrepreneurial activities. Such cooperation enables cities to avoid redundant innovation driven by outdated knowledge, weaken the path dependence of regional development, and further accelerate the reshaping of business models [32]. Technological cooperation networks assist start-ups in overcoming technical bottlenecks and improving overall entrepreneurial performance [33,34]. In addition, the accumulation of professional technical talent generated during technological cooperation optimizes urban human capital structure and provides sufficient talent support for urban digital entrepreneurship [20]. Based on the above analysis, this study proposes the following hypothesis:

H3: *LFC promotes RDE by deepening digital technology cooperation.*

Existing literature suggests that SMEs prefer to explore local knowledge and only search for cross-regional knowledge occasionally when tackling complex problems [35]. Therefore, the process through which Lighthouse Factories acquire external knowledge in their digital transformation exerts a local demonstration effect and enhances the absorptive capacity of neighboring start-ups for emerging digital knowledge. Furthermore, the digital transformation of Lighthouse Factories may induce competitive pressure [15]. Firms' competitive perceptions will drive them to search for knowledge beyond industrial clusters, thereby broadening their knowledge search boundaries [36]. Finally, intercity digital technology transfer and collaboration led by Lighthouse Factories can indirectly accelerate the accumulation of urban digital knowledge. For instance, Ganco argues that the commercialization of basic research is accompanied by tacit knowledge spillovers, which can be preserved within technology incubators after technological incubation [37]. Antunes and Franco [33] argue that technological cooperation promotes technical knowledge sharing and collective learning, thereby reshaping the innovation strategies of micro-enterprises.

The entrepreneurial knowledge spillover theory posits that new knowledge constitutes the origin of entrepreneurial opportunities [38]. Extant literature demonstrates that knowledge accumulation facilitates entrepreneurship through multiple pathways, such as optimizing the entrepreneurial ecosystem, accelerating the accumulation of human capital with complex knowledge endowments, and fostering entrepreneurial culture [37,39]. Although technology transfer, cooperation, and knowledge accumulation are related, they represent different channels: transfer captures market-based circulation of digital technologies, cooperation captures joint innovation activity, and knowledge accumulation captures the absorptive and cognitive stock available for entrepreneurial recombination. Based on the above analysis, this paper proposes the following hypothesis:

H4: *LFC promotes RDE by accelerating urban digital knowledge accumulation.*

Cultivating local industrial competitiveness constitutes the core objective of industrial policy. Extant studies have found that voluntary industrial policies represented by green factories can generate a ripple effect, thereby improving firms' sustainable development performance [40]. In addition, the digital transformation of Lighthouse Factories can accelerate the flow of factors such as digital knowledge and technology, and promote the

upgrading of infrastructure in local digital economy industries. Lau et al. found that the upgrading of industrial infrastructure can boost industrial performance and further enhance the market competitiveness of local enterprises [41]. Furthermore, Peng et al. demonstrate that tangible knowledge flows exert a persistent positive impact on industrial specialization [42]. Supported by the government, Lighthouse Factories cooperate with third-party institutions, summarize their practical experience in digital technology application, translate relevant digital transformation experiences into systematic and standardized methodologies through white papers, and ultimately help enhance the competitiveness of local digital economy industries.

Audretsch et al. argued that the enhancement of competitiveness is a crucial determinant of regional entrepreneurship [26]. In addition, the upgrading of industrial competitiveness can elevate the ecological niche of local enterprises and mitigate market encroachment by outside firms. For instance, De Backer and Sleuwaegen found that foreign direct investment generates a short-term crowding-out effect on local entrepreneurship, yet such an effect can be reversed when demonstration and learning effects are fully realized [43]. Finally, the advancement of local industrial competitiveness can alleviate low entrepreneurial willingness, intergenerational unemployment, and identity deprivation arising from rigid regional informal institutions, thereby fostering entrepreneurial spirit and promoting the development of digital entrepreneurship [44]. Based on the above analysis, this paper proposes the following hypothesis:

H5: *LFC promotes RDE by enhancing local digital industrial competitiveness.*

3. Research Design and Data Description

3.1. Empirical Strategy

To standardize variable definitions and measurement criteria and to enhance the temporal comparability of the data, this paper sets the start year of the sample as 2016. On the one hand, following the launch of the Made in China 2025 initiative in 2015, local governments and enterprises across China began advancing digital transformation around 2016, and the classification standards for digital technology and digital economy industries have since become standardized. On the other hand, the first batch of Lighthouse Factories was released in the second half of 2018, and this paper considers 2019 as the first year of the policy shock. Using panel data starting from 2016 ensures a sufficiently long pre-policy window.

Following Liu et al. [45], this paper takes the certification of the first Lighthouse Factory in each city as a quasi-natural experiment, and adopt the following DID model to examine the impact of LFC on RDE, using China's county-level panel data from 2016 to 2023. This paper considers the timing of LFC as plausibly exogenous conditional on the included controls and fixed effects. Certification decisions are primarily determined by the World Economic Forum in collaboration with international partners based on factories' prior adoption of advanced digital technologies and operational excellence, rather than by contemporaneous local economic conditions or entrepreneurial dynamics within the surrounding counties. Moreover, by incorporating county-level fixed effects, this paper accounts for time-invariant unobserved heterogeneity across counties, while year fixed effects absorb common macroeconomic shocks.

$$RDE_{it} = \delta + \beta_1 LFC_{it} + \beta_x X + v_i + \mu_t + \varepsilon_{it} \quad (1)$$

In the above equation, *RDE* denotes regional digital entrepreneurship, and *LFC* is a dummy variable indicating the policy shock, constructed as the interaction term *Treat* × *Post*. Specifically, subscript *i* refers to county-level cities and *t* represents years. *v_i* represents

county-level city fixed effects, μ_t denotes year fixed effects, and ε_{it} is the random error term. X stands for a vector of control variables. The coefficient β_1 reflects the net effect of LFC on RDE.

3.2. Variable Selection

3.2.1. Dependent Variable

The dependent variable is regional digital entrepreneurship. Digital entrepreneurship is an interdisciplinary field integrating entrepreneurship and digital technologies. It refers to the process of conducting entrepreneurial activities by directly or indirectly adopting or creating digital technologies.

Some studies define digital entrepreneurship as the process of founding new ventures and generating profits by leveraging emerging digital technologies such as the Internet and digital modules. Other studies focus more on the indirect role of digital technologies, defining it as the process of identifying and refining entrepreneurial opportunities through communication technologies, social media, and other digital tools. Furthermore, some definitions highlight the innovation capacity of digital entrepreneurship, regarding it as the process of identifying and exploiting entrepreneurial opportunities through the development of new digital products and services [46].

Following Ptashchenko et al. and Soluk et al. [4,6], this paper measures regional digital entrepreneurship as the number of registered enterprises in digital economy-related industries at the county level, normalized by GDP (in millions of yuan). This paper adopted this measure for three reasons: (1) it normalizes entrepreneurial activity by regional economic scale, allowing meaningful comparisons across counties of different sizes; (2) it follows established practice in the entrepreneurship literature to capture regional entrepreneurial intensity; (3) it helps address heteroskedasticity concerns associated with raw count data.

Corporate registration data are obtained from the Chinese Industrial and Commercial Enterprise Registration Database. The industrial classification of the digital economy follows the criteria of the OECD and the BEA [47,48], which divide the digital economy into three categories: digitally enabled infrastructure, digital media, and digital transactions. This classification covers the core sectors of digital entrepreneurship, with corresponding industry codes in accordance with China's GB/T 4754-2017 [49] as follows: I-63, I-64, I-65, C-39, R-86, R-87, F-51 and F-52. Such entrepreneurial activities involve the direct and indirect application as well as independent innovation of digital technologies. The industries related to the digital economy, along with their respective codes and names defined by GB/T 4754-2017, are presented in Appendix A.

3.2.2. Core Explanatory Variable

The core explanatory variable is Lighthouse Factory certification. This paper treats the certification of each city's first Lighthouse Factory as a quasi-natural experiment. The certification list covers the first ten batches released by the World Economic Forum from the second half of 2018 to the first half of 2023.

Existing studies have shown that comparable policies generate economic effects at the prefecture-city level and exert significant spatial spillover effects on neighboring cities [50]. Therefore, selecting only county-level cities with Lighthouse Factories as the treatment group may lead to a "bad control group" problem. Specifically, county-level cities within the same prefecture-level city—though not hosting a Lighthouse Factory themselves—are likely influenced by spillover effects, leading to changes in the digital entrepreneurship environment. If they are incorrectly assigned to the control group, the estimated treatment effect will be biased. To address this, this paper defines all county-level cities under the jurisdiction of the prefecture-level city hosting the first Lighthouse Factory as the treatment

group. The dummy variable *Treat* takes the value of 1 for such cities and 0 otherwise. Notably, while this approach mitigates endogeneity concerns, it may underestimate the economic impact of Lighthouse Factory certification. This is because the policy effect actually captures the average of the direct policy effect and the policy spillover effect. Nevertheless, between the two potential biases—underestimation due to treating spillover-affected samples as the treatment group versus endogeneity caused by a bad control group—this paper considers the latter more harmful to causal identification. Hence, this paper adopts the strategy of treating all county-level cities under the prefecture-level city exposed to the policy shock as the treatment group.

In addition, as the official release date of the Lighthouse Factory list varies across months, this paper considers lists announced in the first half of a year as policy shocks in the current year, and those released in the second half as shocks in the following year. The dummy variable *Post* is set to 1 for the policy implementation year and all subsequent years, and 0 otherwise.

3.2.3. Control Variables

Following existing studies [26], we adopt the following county-level control variables: market size (natural logarithm of total population), income level (GDP per capita), urban-rural structure (proportion of rural population in registered permanent population), industrial structure (ratio of tertiary to secondary industry value added), government intervention (ratio of general budgetary fiscal expenditure to GDP), and institutional environment (natural logarithm of the number of beds in social welfare institutions). The raw data are sourced from the China County Statistical Yearbook. Missing data are imputed via linear interpolation. For continuous variables with occasional missing years, we applied linear interpolation. Imputed observations account for approximately 4.7% of the full sample. To ensure that the imputation method does not drive our core conclusions, we also re-estimated the baseline model using the original unbalanced panel without interpolation. The results show that the coefficient sign and significance level of the core explanatory variable remain consistent with the baseline findings. Descriptive statistics are reported in Table 1.

Table 1. Descriptive statistics of variables.

Variable	Mean	Std	Min	Max	Obs
RDE	0.17	0.29	0.00	18.40	20,735
LFC	0.04	0.19	0.00	1.00	20,735
Transfer	1.25	1.53	0.00	8.88	20,735
Cooperation	1.64	1.83	0.00	9.17	20,735
Knowledge	0.05	0.24	0.00	3.50	20,735
Expansion	2.18	1.76	0.00	10.33	20,735
Income level	6.05	4.88	1.11	28.57	20,735
Market size	3.61	0.82	1.10	5.13	20,735
Urban-rural structure	0.78	0.40	0.02	2.72	20,735
Industrial structure	1.68	1.56	0.25	10.50	20,735
Government intervention	0.28	0.28	0.03	1.64	20,735
Institutional environment	6.94	1.16	3.91	9.05	20,735

4. Empirical Results and Analysis

4.1. Baseline Regression Results

This section analyzes the impact of LFC on RDE. The regression results are reported in Table 2. Counties with a Lighthouse Factory certification have an RDE level 4.58% higher than that of non-certified counties. Taking the 25th percentile (0.0848) and 75th percentile (0.1845) of RDE, this paper calculates the interquartile range (IQR) as 0.0997. This coefficient accounts for approximately 45.94% of the IQR of county-level RDE. These results support Hypothesis 1, suggesting that in the early stage of digital transformation in developing countries, most cities lack accumulated experience in this regard. Cultivating leading enterprises for digital transformation can therefore generate a notable policy effect and effectively promote RDE.

Table 2. Results of baseline regression.

	(1) RDE	(2) RDE	(3) RDE	(4) RDE
LFC	0.0051 (0.0105)	0.0236 * (0.0123)	0.0701 *** (0.0118)	0.0458 *** (0.0108)
Control	N	Y	Y	Y
City Fe	N	N	Y	Y
Year FE	N	N	N	Y
Constant	0.1704 *** (0.0021)	0.0645 *** (0.0179)	2.6215 *** (0.5922)	2.6595 *** (0.5899)
Observations	20,735	20,735	20,735	20,735
R2	0.0000	0.0384	0.4975	0.5008

Note: *** $p < 0.01$, * $p < 0.10$. Robust standard error in brackets. N indicates that the fixed effects and control variables are not controlled for, while Y indicates that they are controlled for.

4.2. Robustness Test

Based on a series of robustness checks, the core findings of this paper remain highly reliable. The parallel trend test confirms that no significant differences in digital entrepreneurship existed between treatment and control counties prior to Lighthouse certification, while the placebo test rules out random chance as a driver of the results. Bacon decomposition indicates that 97.3% of the identifying variation comes from comparisons between treated and never-treated units, with consistent estimates across subgroups. Furthermore, the results hold under PSM-DID with multiple matching strategies, stacked DID, controlling for other digital policies, excluding megacity samples, and removing core cities in digital technology and knowledge spillover networks to mitigate long-distance spillover effects. Collectively, these tests demonstrate that our baseline estimates are not driven by sample selection, omitted variables, policy confounding, or spatial interference, supporting the robustness and external validity of our conclusions. Detailed results of the robustness tests are reported in Appendix B.

4.3. Heterogeneity Analysis

First, following the text-based environmental regulation measurement approach of Zhu et al. [51], this paper examines the heterogeneous effects of LFC on RDE across cities with different environmental regulation intensities. The results (see Table 3) show that the promoting effect of LFC on RDE is more pronounced in cities with stricter environmental regulations. Since manufacturing firms inevitably generate pollutants during production, stringent environmental regulations impose rigid institutional constraints that compel these firms—including lighthouse factories and their peers—to accelerate digital transformation.

Such changes amplify the demonstration and spillover effects of lighthouse factories, thereby reinforcing their impact on RDE.

Table 3. Results of heterogeneity analysis.

	Environmental Regulation		Green Transition Climate		Digital Infrastructure	
	High (1) RDE	Low (2) RDE	High (3) RDE	Low (4) RDE	High (5) RDE	Low (6) RDE
LFC	0.0639 *** (0.0179)	0.0250 * (0.0142)	0.0651 *** (0.0153)	0.0049 (0.0105)	0.0452 *** (0.0129)	0.0299 ** (0.0138)
Control	Y	Y	Y	Y	Y	Y
City Fe	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Constant	2.7479 *** (0.8839)	3.0101 *** (0.9999)	3.9563 *** (0.8087)	0.2535 ** (0.1242)	3.5070 *** (0.8168)	1.1158 ** (0.5344)
Fisher's Statistic	0.039*		0.0060 **		0.015	
Observations	10,569	9575	9246	10,913	9457	10,743
R2	0.5820	0.5973	0.5929	0.3905	0.5597	0.4612

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

Second, this paper uses the number of green factories to capture regional green transformation climate and further analyze the heterogeneous effects of LFC on RDE. The results indicate that the positive impact of LFC on RDE is magnified in regions with a stronger green transformation climate. In regions with strong green development awareness and established practical foundations, the digital transformation experience of leading firms is more readily accepted, learned, and diffused. Together, these findings confirm that stringent environmental regulations and greater regional green development awareness can indirectly amplify the economic outcomes of leading enterprises' digital transformation. This further implies that urban green transformation and digital transformation work synergistically to stimulate digital entrepreneurship in the context of digital-green integrated development. These findings create new scope for the coordination of digital and green economy policies, which implies that SDG 8 and SDG 9 may be jointly delivered with other SDGs, including SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).

Third, this paper uses the urban internet penetration rate as a proxy for regional digital infrastructure endowment to explore heterogeneous impacts across regions with varying digital infrastructure conditions. Contrary to conventional expectations, the positive effect of LFC on RDE is not significantly weaker in regions with insufficient digital infrastructure. This finding reveals that the digital transformation of leading enterprises can still effectively promote local digital entrepreneurship even in small and medium-sized cities and less developed areas with underdeveloped digital infrastructure, which brings fresh policy implications for the joint implementation of SDG 8, SDG 9 and SDG 10 (Reduced Inequalities).

5. Mechanism Analysis

5.1. Digital Technology Transfer

This paper uses digital patent transaction data from county-level cities to measure the intensity of intercity digital technology transfer. First, this paper collected complete patent assignment transaction data from the China Patent Publication Announcement platform of the National Intellectual Property Administration and excluded transactions involving

foreign entities as either the assignor or the assignee. Given that digital entrepreneurship involves the digital transformation and application of traditional technologies, this paper adopted a broad standard for screening digital patents. Following the Classification System of Key Digital Technology Patents (2023) [52], this paper identified and retained all patents containing digital technologies based on their patent classification numbers. Second, this paper extracted detailed addresses from the assignor and assignee information and classified assignees at the county level. This paper supplemented any missing enterprise addresses using data from AutoNavi Map and excluded transactions with unavailable address information. Finally, this paper aggregated patent assignment volumes at the county level and calculated the natural logarithm after adding one to obtain the digital technology transfer intensity received by each county-level city from intra-city and intercity sources.

The following analysis examines the mediating role of digital technology transfer in the influence of LFC on RDE (see Table 4). Model 1 shows that LFC significantly promotes intercity digital technology transfer at the 1% significance level. After controlling for the effect of LFC in Model 2, digital technology transfer still has a significant impact on RDE. This result suggests that digital technology transfer may accelerate digital entrepreneurship by increasing the supply of digital technologies, expanding technical application scenarios, and enriching digital entrepreneurial opportunities. This paper further employs the bootstrap method with 1000 resampling iterations to test the significance of the indirect effect. Unlike the traditional three-step method, the advantage of the bootstrap approach is that it directly tests whether the indirect effect is significant and provides its confidence interval, rather than relying on the logical inference based on the significance of individual coefficients in a series of regressions. The results show that the indirect effect of digital technology transfer is significant at the 5% level, with a 95% confidence interval that does not include zero. The regression results from Models 1 and 2 validate Hypothesis H2, demonstrating that LFC facilitates RDE by promoting digital technology transfer.

Table 4. Results of mechanism analysis.

	Digital Technology Transfer		Digital Technology Cooperation	
	(1) Transfer	(2) RDE	(3) Cooperation	(4) RDE
LFC	0.2814 *** (0.0345)	0.0429 *** (0.0108)	0.1709 *** (0.0302)	0.0445 *** (0.0108)
transfer		0.0104 *** (0.0022)		
cooperation				0.0076 *** (0.0023)
Bootstrap IE		0.0004 ***		0.0003 **
Control	Y	Y	Y	Y
City Fe	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Constant	−0.5305 * (0.3068)	2.6650 *** (0.5898)	0.3804 (0.2788)	2.6566 *** (0.5891)
Observations	20,735	20,735	20,735	20,735
R2	0.8328	0.5013	0.8859	0.5010

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

5.2. Digital Technology Cooperation

This section uses the number of digital patents co-applied by county-level cities with other cities to measure the intensity of intercity digital technology cooperation. Using patent application data published by the National Intellectual Property Administration, this paper identifies patents involving applicants from other county-level jurisdictions based on multi-applicant information and retain only those patents with cross-county collaboration. Digital technologies are screened using the broad standard mentioned above. The number of co-applied digital patents is aggregated at the county level according to the applicants' addresses. This paper then takes the natural logarithm of this value plus one to obtain the digital technology cooperation intensity for each county relative to other regions.

The results presented in Models 3 and 4 of Table 4 show that LFC significantly promotes digital technology cooperation across county-level cities at the 1% significance level. In Model 4, after incorporating both digital technology cooperation and LFC into the econometric model and controlling for the effect of LFC, digital technology cooperation still exhibits a significantly positive impact on RDE, confirming that digital technology cooperation drives RDE. The regression results validate Hypothesis H3, demonstrating that LFC enhances RDE by boosting cross-city digital technology cooperation.

5.3. Digital Knowledge Accumulation

This section measures intercity digital knowledge spillover based on digital patent citation frequencies across county-level cities. Digital technology patents are screened in accordance with the foregoing standards. This paper aggregates the citation frequency of digital patents originating from other cities at the county level and calculates the natural logarithm of the total value plus one to measure the intensity of county-level digital knowledge accumulation.

As presented in Model 1 of Table 5, LFC significantly facilitates cities' ability to absorb digital knowledge from external areas and enhance their local digital knowledge stock, thereby building a solid knowledge base for regional digital entrepreneurship. Building on Model 1, Models 2 and 3 further investigate the indirect knowledge spillover effects of digital technology transfer and cooperation. After controlling for LFC, both factors exert significant positive effects on digital knowledge accumulation, implying that LFC boosts knowledge accumulation via direct and indirect channels. Model 4 shows that digital knowledge accumulation still exerts a positive influence on RDE when LFC is controlled. The empirical results validate Hypothesis H4, demonstrating that LFC promotes RDE by facilitating county-level digital knowledge accumulation.

Table 5. Results of mechanism analysis.

	Digital Knowledge Accumulation				Industrial Competitiveness	
	(1) Knowledge	(2) Knowledge	(3) Knowledge	(4) RDE	(5) Expansion	(6) RDE
LFC	0.1150 *** (0.0215)	0.1132 *** (0.0215)	0.1146 *** (0.0215)	0.0434 *** (0.0104)	−1.0340 *** (0.0325)	0.0379 *** (0.0121)
transfer		0.0063 *** (0.0015)				
cooperation			0.0023 * (0.0013)			
knowledge				0.0212 ** (0.0093)		
expansion						−0.0077 * (0.0045)

Table 5. *Cont.*

	Digital Knowledge Accumulation				Industrial Competitiveness	
	(1) Knowledge	(2) Knowledge	(3) Knowledge	(4) RDE	(5) Expansion	(6) RDE
Bootstrap IE		0.0007 ***	0.0003 **	0.0009 **		−0.0003 **
Control	Y	Y	Y	Y	Y	Y
City Fe	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Constant	−0.3875 *** (0.0789)	−0.3841 *** (0.0787)	−0.3883 *** (0.0788)	2.6677 *** (0.5911)	2.0562 *** (0.3684)	2.6752 *** (0.5910)
Observations	20,735	20,735	20,735	20,735	20,735	20,735
R2	0.6619	0.6622	0.6619	0.5009	0.9299	0.5009

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

5.4. Competitiveness of Local Digital Industry

Due to the unavailability of direct data on industrial competitiveness and enterprise market share at the county level, this section uses the hiring data of external enterprises in county-level cities to indirectly measure their business expansion and, in turn, examine the promoting effect of LFC on the competitiveness of local digital industries.

First, this paper obtained complete corporate hiring data from 51 jobs. To ensure comparability over time, this paper retained only recruitment information from listed companies, their subsidiaries, associated enterprises, and joint ventures, while removing duplicate entries. Second, digital economy-related industries were identified following the aforementioned standards, including eight industries with codes I63, I64, I65, C39, R86, R87, F51, and F52 according to the Industrial Classification of National Economy. Finally, external enterprises are defined as entities whose headquarters are located outside the focal county-level city but have local subsidiaries, associated enterprises, or joint ventures. This paper aggregates their hiring volume at the county level and calculates the natural logarithm of this value plus one to measure the business expansion of external enterprises.

The mechanism analysis results are presented in Table 5. Models 5 and 6 explore how LFC affects the market expansion of external digital economy enterprises. The findings reveal that LFC significantly constrains the business expansion of external enterprises. This negative relationship suggests that LFC strengthens the competitiveness of local digital industries, as a stronger local presence tends to limit the market share and expansion of external entrants, thereby boosting RDE. The regression results confirm Hypothesis H5, demonstrating that LFC promotes RDE by enhancing the competitiveness of county-level local digital industries. The negative effect on external enterprise expansion is interpreted as indirect evidence of stronger local digital industrial competitiveness; however, this proxy may also capture changes in market entry conditions, so the mechanism should be read as suggestive rather than definitive.

It should be noted that this paper interprets reduced hiring by external enterprises as evidence of stronger local competitiveness rather than weaker external demand or higher entry barriers, for the following reasons. First, during the same post-LFC period, the number of registered local digital firms and their survival rates increased significantly, indicating that overall local market demand did not contract, thereby partially ruling out the alternative explanation of weaker external demand. Second, a core requirement of the LFC program is that certified enterprises must share their transformation experiences and technical solutions with other local firms. This institutionalized knowledge diffusion mechanism lowers the technological imitation costs for local enterprises rather than raising

entry barriers for external firms. Based on the above analysis, this paper interprets this phenomenon as indirect evidence of enhanced local industrial competitiveness.

6. Further Analyze: Spatial Spillover Effect of LFC

6.1. Neighborhood Spillover Effect

Referring to Fabrizio et al. [23], this paper specifies the following econometric model to analyze the spatial spillover effect of LFC.

$$RDE_{it} = \delta + \beta_1 LFC_{it} + \sum_{s=50}^{300} \delta_s N_{it}^s + \beta_x X + v_i + \mu_t + \varepsilon_{it} \quad (2)$$

Compared with the baseline regression model, this specification introduces a new set of variables, N_{it}^s . The symbol s represents the spatial distance between counties, measured by Euclidean distance. Specifically, N_{it} equals 1 if a lighthouse factory is located within a given distance range (e.g., 0–50 km) from county i in year t , and 0 otherwise. A positive δ_s indicates that lighthouse factories generate a radiation effect on RDE in neighboring counties within the corresponding distance range, while a negative value reflects a siphon effect.

The empirical results show that LFC exerts a siphon effect on digital entrepreneurship in adjacent counties within 0–50 km. Leveraging policy advantages and factor absorption capacity, LFC attracts capital, talent, and market opportunities within this radius, thereby inhibiting RDE. In the 50–150 km range, LFC plays a positive radiating role in neighboring digital entrepreneurship. On the one hand, formal collaboration and informal communication bring substantial knowledge spillovers. On the other hand, high-tech innovation demands supportive service facilities, which fosters industrial agglomeration between LFC and surrounding digital ventures and increases RDE. Within the 250–300 km scope, indirect transmission paths—such as digital technology output, standardized digital service delivery, and cross-county industrial chain division—generate a secondary boosting effect on nearby digital entrepreneurship. Figure 2 confirms that LFC has significant spatial spillover effects on surrounding areas, and these effects exhibit complex non-monotonic distance heterogeneity.

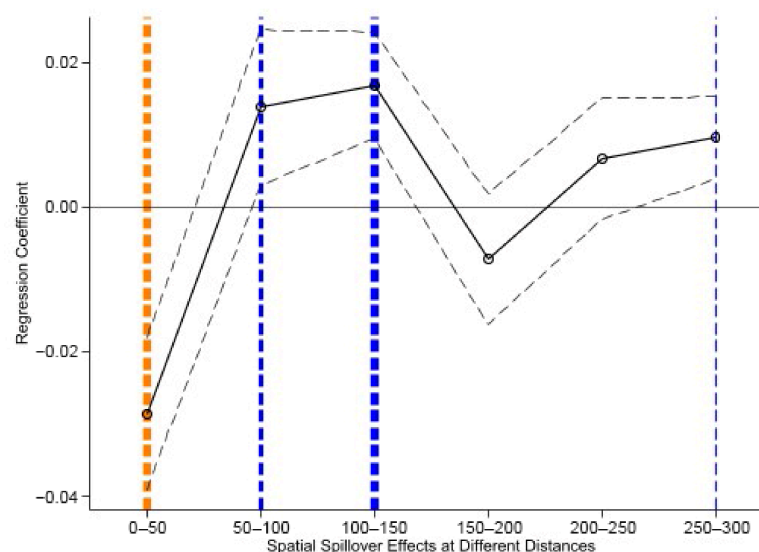


Figure 2. Distance heterogeneity of spatial spillover effects. The blue and orange lines represent the positive spillover effect and the negative siphon effect, respectively. The thickness of the blue line indicates the strength of the spillover effect.

6.2. Network Spillover Effect

Apart from the spatial spillover effect on neighboring cities, LFC can affect the RDE of other cities through urban networks. For example, the growing demand for digital technology at the county level can boost technological development in technology-supplying cities. It further generates spillover effects on digital entrepreneurship by reducing digital technology costs, accelerating technology applications and driving the transformation of digital business models.

Accordingly, this section analyzes the impact of LFC on digital entrepreneurship of associated counties in digital technology transfer networks, digital technology cooperation networks and digital knowledge spillover networks. The econometric model is specified as follows:

$$RDE_{it} = \delta + \beta_1 LFC_network_{it} + \beta_x X + v_i + \mu_t + \varepsilon_{it} \quad (3)$$

In the equation, county i represents county-level cities free from direct policy impacts, excluding all counties under the prefecture-level city where LFC is situated. This setting removes disturbances from direct policy shocks and captures the pure indirect spatial spillover effect of demonstration projects transmitted through urban networks. $LFC_network$ indicates the policy shock ($Treat \times Post$) caused by the first LFC of associated cities of county i . β_1 denotes the spillover influence of the initial LFC accreditation of associated cities on county i .

Six policy shock variables are constructed: (1) $LFC_transfer_a$: Determined by the strongest associated city in the digital technology transfer network. This paper screens the county with the highest total digital technology transfer volume to county i during 2016–2023. County i is considered subject to synchronous policy shock once this county obtains its first LFC. (2) $LFC_transfer_b$: Determined by the earliest treated city in the digital technology transfer network. Among counties conducting digital technology transfer with county i , the earliest LFC-certified city is selected to judge the synchronous policy shock on county i . (3) $LFC_cooperation_a$: Constructed in the same manner based on the strongest associated city in the technology cooperation network. (4) $LFC_cooperation_b$: Constructed in the same manner based on the earliest treated city in the technology cooperation network. (5) $LFC_knowledge_a$: Constructed in the same manner based on the strongest associated city in the knowledge spillover network. (6) $LFC_knowledge_b$: Constructed in the same manner based on the earliest treated city in the knowledge spillover network.

The regression results are reported in Table 6. Models 1 and 2 show that LFC produces positive spillover effects on digital entrepreneurship of counties connected via technology transfer networks. Models 3 and 4 confirm positive spillover effects on counties linked by technology cooperation networks. Models 5 and 6 illustrate that LFC does not produce statistically significant spillover effects on digital entrepreneurship within knowledge spillover networks.

Table 6. Results of network spillover effect.

	(1) RDE	(2) RDE	(3) RDE	(4) RDE	(5) RDE	(6) RDE
LFC_transfer_a	0.0244 *** (0.0057)					
LFC_transfer_b		0.0336 *** (0.0051)				
LFC_cooperation_a			0.0282 *** (0.0060)			
LFC_cooperation_b				0.0299 *** (0.0057)		

Table 6. Cont.

	(1) RDE	(2) RDE	(3) RDE	(4) RDE	(5) RDE	(6) RDE
LFC_knowledge_a					0.0083 (0.0277)	
LFC_knowledge_b						0.0157 (0.0271)
Control	Y	Y	Y	Y	Y	Y
City Fe	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Constant	2.8093 *** (0.6571)	2.8120 *** (0.6570)	2.8085 *** (0.6566)	2.8042 *** (0.6567)	2.8000 *** (0.6582)	2.8047 *** (0.6587)
Observations	18,968	18,968	18,968	18,968	18,968	18,968
R2	0.4900	0.4904	0.4902	0.4902	0.4896	0.4896

Note: *** $p < 0.01$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

7. Discussion

Digital entrepreneurship can not only drive regional economic growth but also trigger creative destruction, reshape market competition, and advance institutional reform, thus having profound implications for urban sustainable development. This paper examines the impact of leading enterprises' digital transformation on regional digital entrepreneurship. The findings show that Lighthouse Factory certification promotes regional digital entrepreneurship by facilitating digital technology transfer, deepening digital technology cooperation, accelerating digital knowledge accumulation, and enhancing local digital industrial competitiveness. In addition, significant spatial spillovers emerge among neighboring and network-linked cities through regional digital technology transfer and cooperation networks.

This paper deepens the understanding of enterprise digital transformation's impacts and strengthens its theoretical link to digital entrepreneurship. Most existing studies focus on internal effects, such as innovation performance, production efficiency, and market competitiveness. A few have examined supply chain spillovers, but they largely neglect spatial externalities and the role of enterprise digital transformation in optimizing regional digital entrepreneurial environments. By addressing this gap, this paper offers a more comprehensive view of the social value generated by enterprise digital transformation.

It should be noted that generalizing the effects of digital transformation from leading enterprises to ordinary enterprises is not automatic and requires certain preconditions. Specifically, the magnitude of peer effects triggered by enterprise digital transformation merits careful consideration, a topic that has been explored to some extent in prior studies [28]. The Lighthouse Factories investigated in this paper are leading enterprises with strong demonstration effects, and their demonstration role has received substantial support from local governments. Consequently, their digital transformation generates significant peer effects, which in turn produce spillover effects on regional digital entrepreneurship.

A parallel strand of research focuses on the effects of leading enterprises on SMEs, with prior studies presenting two contradictory perspectives—namely, the pull effect and the crowding-out effect [10,11,15]. Contributing to this debate, this paper finds that leading enterprises exert demonstration effects, thereby improving the regional entrepreneurial environment and promoting digital entrepreneurship—a finding that aligns with the information spillover effect identified by Wang & Wang and the knowledge spillover effect reported by Liu et al. in terms of impact mechanisms [15,18]. However, most prior studies on leading enterprises concentrate on their impact on competing SMEs and industrial chain

entities, leaving start-ups largely underexplored. This finding thus fills this important gap in the literature.

In entrepreneurship research, as entrepreneurial ecosystem theory evolves, scholars have increasingly focused on the regional environment of entrepreneurial activities. Prior literature has examined geographical determinants of digital entrepreneurship, including digital technological affordance [3], local administrative approval reforms [4,5], and access to skilled labor [20]. While numerous studies confirm that favorable regional environments boost digital entrepreneurship, few have thoroughly investigated how to build, cultivate, and optimize such environments. This mechanism analysis reveals that the digital transformation of leading enterprises facilitates technology transfer, deepens technological cooperation, accelerates knowledge accumulation, and enhances local industrial competitiveness. These mechanisms collectively reveal how the strategic cultivation of leading enterprises can improve the regional digital entrepreneurship environment.

In addition, this paper systematically explores the spatial spillover effects of leading enterprises' digital transformation. Prior research has verified such effects in the context of space-oriented policies that facilitate digital economic development [48]. Adopting existing analytical paradigms, this paper further differentiates between the siphon effect and the spread effect of leading enterprises' digital transformation on regional digital entrepreneurship, and identifies the distance scope within which each effect operates. Moreover, the findings show that enterprise digital transformation can generate cross-city spatial spillovers through regional technology transfer and cooperation networks. This finding not only offers novel insights but also introduces a methodological approach for examining such cross-city spillovers.

Finally, the heterogeneity analysis offers novel research directions and theoretical implications for future research. A key theoretical implication emerging from this analysis is the significant synergy between digital and green transformation. Specifically, the study finds that the positive effect of leading enterprises' digital transformation on regional digital entrepreneurship is more pronounced in regions with stringent environmental regulations and a strong green transition climate. While Lyu et al. [53] document that green pressures can drive firms' internal digital transformation, how green development affects the externalities of corporate digital transformation—particularly its spillover effects on regional entrepreneurship—remains underexplored.

Beyond its theoretical contributions, this paper also yields several policy implications. As traditional production factors exhibit diminishing marginal effects on global economic growth, scholars and practitioners are increasingly concerned with how digital transformation can jointly advance SDG 8 and SDG 9. This paper proposes a tentative policy direction for cultivating leading enterprises to promote regional entrepreneurship, employment, and industrial development.

On the one hand, the digital transformation of leading enterprises exerts demonstration effects. Prior research has identified digital competencies of SMEs as a key driver of digital transformation in emerging economies [54]. It may boost manufacturing R&D and technological application and accelerate the upgrading of next-generation digital infrastructure. This may consolidate the industrial foundation for the digital economy and facilitate the achievement of SDG 9. On the other hand, such transformation drives regional digital entrepreneurship and creates numerous jobs in technological R&D, digital operations, intelligent services, and related fields. It effectively promotes decent employment, accelerates the transformation of regional economic growth drivers, and helps achieve SDG 8.

A core challenge for industrial policies aiming at sustainable development is reducing coordination costs among large enterprises, SMEs, and start-ups. By revealing how digital transformation improves the regional entrepreneurial environment through spillover

effects—a channel largely overlooked in the prior literature—this paper helps policymakers better recognize the social returns of digital economy policies and avoid decisions based on partial findings. If policymakers focus only on firm-level benefits, they may neglect to design mechanisms that amplify regional positive externalities. Consequently, digital dividends may be captured by a small number of enterprises rather than shared across the entire regional economy.

Furthermore, this paper finds that the impact of leading enterprises' digital transformation on regional digital entrepreneurship presents regional heterogeneity, which opens up new possibilities for the coordinated achievement of SDGs. On the one hand, such impact is more pronounced in regions with stricter environmental regulations and a more favorable climate for green transformation, suggesting that digital and green policy goals can be mutually reinforcing. This finding creates new scope for the coordination of digital and green economy policies, which implies that SDG 8 and SDG 9 may be jointly delivered with other SDGs, including SDG 12 and SDG 13. On the other hand, local digital infrastructure exerts little restriction on this impact. It follows that digitally transformed leading enterprises are able to stimulate local digital entrepreneurship across small and medium-sized cities and less developed regions with insufficient digital infrastructure, which brings fresh policy implications for the joint implementation of SDG 8, SDG 9 and SDG 10.

8. Conclusions and Policy Recommendations

8.1. Conclusions

Enterprise digital transformation is not only a contextual reality but also a key driver of regional innovation and entrepreneurship. A core question for achieving SDGs 8 and 9 in a coordinated manner is how governments can design timely and effective interventions to harness the externalities generated by enterprise digital transformation, thereby fostering local digital entrepreneurship and cultivating endogenous growth momentum. Using the Lighthouse Factory certification as a quasi-natural experiment, this paper employs Chinese county-level panel data from 2016 to 2023 and adopts a DID model to examine the impact of leading enterprises' digital transformation on regional digital entrepreneurship. The main findings of this paper are as follows:

- (1) Empirical results show that the LFC significantly promotes RDE, a finding that remains robust after adopting a series of methods including PSM-DID and stacked DID.
- (2) Heterogeneity analysis reveals that this facilitating effect of LFC on RDE is stronger in regions with stricter environmental regulations and a stronger green transformation climate, while it is not significantly constrained by local digital infrastructure endowment. These findings jointly facilitate the coordinated implementation of SDG 8, SDG 9, SDG 10, SDG 12 and SDG 13.
- (3) Mechanism analysis indicates that LFC enhances RDE by promoting digital technology transfer, deepening digital technology cooperation, accelerating digital knowledge accumulation, and improving the competitiveness of local digital industries.
- (4) Spatial spillover analysis shows that LFC exerts positive spillovers on cities located 50–150 km and over 250 km away, but exerts a significant siphon effect on cities within 50 km.
- (5) Network spillover analysis further reveals that LFC yields positive network spillovers on economically linked cities through regional digital technology transfer and cooperation networks, while having no significant impact on cities connected via knowledge spillover networks.

This paper clarifies the interaction between leading enterprises and start-ups in digital transformation, enriches the literature on digital entrepreneurship, and provides empir-

ical evidence for leveraging the demonstration effect of leading enterprises to promote sustainable development.

8.2. Policy Recommendations

First, optimize supporting policies for leading enterprises' digital transformation and amplify their demonstration capacity to empower regional digital entrepreneurship, so as to advance the coordinated implementation of SDG 8 and SDG 9. Governments should expand the coverage of digital transformation demonstration programs for leading enterprises and establish a dynamic evaluation mechanism. Specifically, continuous policy support and funding incentives should be granted to enterprises with outstanding demonstration effects, while targeted optimization and adjustment should be implemented for ineffective transformation practices, so as to steadily strengthen the driving force of leading enterprises for local digital entrepreneurship. Furthermore, local governments should guide leading enterprises to align their digital transformation practices with county-level characteristic industries, promote the in-depth integration of digital technologies with agriculture, manufacturing, and service sectors, and foster new business forms and models of regional digital entrepreneurship. This translates the technological advantages of leading enterprises into tangible momentum for industrial upgrading and high-quality employment growth. In addition, improving public digital literacy and strengthening county-level digital talent training can consolidate human capital foundations for inclusive digital entrepreneurship, facilitating the realization of inclusive economic growth and innovative industrial development under SDG 8 and SDG 9. Policy support for leading digital enterprises should be accompanied by mechanisms that prevent excessive concentration of talent, capital, and opportunities in the immediate vicinity of certified firms, particularly in counties located within the observed siphon-effect radius.

Second, improve cross-regional digital technology transfer, cooperation and spatial spillover mechanisms to bridge regional development gaps, which supports the synergistic implementation of SDG 8, SDG 9 and SDG 10. Local authorities should build cross-county digital technology service and R&D platforms to integrate superior digital resources, streamline technology transfer procedures, and encourage leading enterprises and research institutions to establish collaborative technology transformation mechanisms with local start-ups, accelerating the localized application of digital achievements. Governments can launch targeted incentives such as tax reductions and financial subsidies to mobilize cross-regional technological cooperation and shorten the innovation and transformation cycle. In addition, it is necessary to standardize cross-regional technology transfer rules and improve intellectual property protection systems to give full play to the positive spatial and network spillover effects of leading enterprises on economically linked and distant regions. This enables underdeveloped regions and small and medium-sized cities to fully share digital entrepreneurial dividends, promotes inclusive employment and industrial innovation across regions, and effectively narrows regional economic and technological gaps, thus advancing the inclusive and coordinated development of SDG 8, SDG 9 and SDG 10.

Finally, leverage the policy synergy between digital economy and green economy to fully release the entrepreneurial empowerment effect of leading enterprises, thereby promoting the coordinated realization of SDG 12 and SDG 13. Given that the driving effect of leading enterprises' digital transformation on digital entrepreneurship is more prominent in regions with stricter environmental regulations and sounder green transformation atmosphere, local governments should actively build a collaborative policy system integrating digital transformation and green development. It is essential to match digital incentive policies with green low-carbon governance policies, guide leading enterprises

to drive green and digital dual transformation of regional industries, and promote the popularization of new production technologies and efficient resource allocation.

8.3. Limitations and Future Research

First, because the empirical data were collected after China initiated its digital transformation in 2016, the generalizability of the conclusions is subject to contextual boundaries. China's institutional environment—characterized by strong government coordination capacity, rapid digital infrastructure development, and large domestic market scale—may shape the magnitude and direction of spillover effects in ways that differ from other national settings. Nonetheless, these findings provide meaningful implications for other emerging economies undergoing similar digital catch-up processes, particularly those implementing industrial policies centered on benchmark or leading enterprises. For developed economies, the mechanisms identified may operate through different channels or with varying intensity due to differences in market structure, regulatory frameworks, and innovation systems. Cross-country comparative research is therefore needed to assess the external validity of these findings. At the same time, China's experience offers a relevant reference for understanding how state-guided digital transformation can generate regional entrepreneurial spillovers, an insight that may inform policy design in other developing contexts while remaining attentive to local institutional particularities.

Second, this paper references the SDGs primarily for broad inspirational purposes, rather than as a core component of empirical testing. Discussions regarding the contribution to the SDGs should be understood as extensions of the policy implications derived from the research findings, rather than as empirical evidence of the degree of SDG achievement. This study does not directly measure any SDG indicators, nor does it incorporate goals such as SDG 8, 9, 10, 12, or 13 into the econometric model as dependent variables or moderating variables. Instead, the SDGs are employed as a macro policy context to highlight the practical significance of studying digital entrepreneurship and the spillover effects of leading enterprises' digital transformation. In future research, this paper will incorporate the SDGs into the theoretical analytical framework to guide the formulation of heterogeneity analysis directions and the hierarchical division of policy implications, thereby elevating the SDGs from a background context to an integral component of theoretical construction.

Finally, several limitations regarding the measurement of digital entrepreneurship should be acknowledged. First, the dependent variable captures registered digital-economy firms, which reflects firm entry rather than entrepreneurial quality, innovation intensity, or long-term survival. It is possible that some registered firms are inactive, low-growth, or short-lived, and our primary measure does not distinguish between high-potential startups and marginal entrants. Second, data limitations prevent a more nuanced assessment of firm-level innovation outputs or productivity growth. Third, the use of GDP as a denominator in the main specification, although useful for normalizing regional economic scale, introduces potential endogeneity concerns given the bidirectional relationship between digital entrepreneurship and local economic output. Future research could extend this analysis by incorporating firm-level panel data to track entrepreneurial quality indicators such as patent applications, employment growth, or venture capital financing.

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Appendix A

The industrial classification of the digital economy follows the criteria of the OECD and the BEA [45,46], which divide the digital economy into three categories: digitally enabled infrastructure, digital media, and digital transactions. The industries related to the digital economy, along with their respective codes and names defined by GB/T 4754-2017, are presented in Table A1.

Table A1. Digital economy-related industries and their industry codes.

Category	Code	Industry Name
Digital Enabling Infrastructure	I-63	Telecommunications, Radio, Television and Satellite Transmission Services
	I-64	Internet and Related Services
	I-65	Software and Information Technology Services
	C-39	Computer, Communication and Other Electronic Equipment Manufacturing
Digital Media	R-86	News and Publishing
	R-87	Radio, Television, Film and Audio-Visual Production
	I-64	Internet and Related Services
	I-65	Software and Information Technology Services
Digital Transaction	F-51	Wholesale
	F-52	Retail

Appendix B

This paper adopts multiple methods to conduct robustness tests on the baseline regression results to verify the reliability of the research conclusions.

(1) Parallel Trend Test

The parallel trend assumption is a core prerequisite for the validity of the difference-in-differences (DID) model. This paper takes one year before the certification of Lighthouse Factories as the benchmark period and constructs the following model for the parallel trend test:

$$RDE_{it} = \beta_0 + \beta_k \sum_{k \geq -4} LFC_{it}^k + \gamma X + v_i + \mu_t + \varepsilon_{it} \quad (A1)$$

In the formula above, *LFC* denotes the dummy variable of Lighthouse Factory certification, and *k* represents the time window of policy shock. The definitions of other variables are consistent with those in the previous analysis. Figure A1a plots the estimated coefficients β_k and their 90% confidence intervals. The results show that there is no significant difference in the level of digital entrepreneurship between the treatment and control counties before the policy shock. In contrast, a significant disparity emerges after the implementation of LFC, which verifies that the model satisfies the parallel trend assumption.

(2) Placebo Test

The placebo test results indicate that most *p*-values lie above the horizontal dashed line ($p = 0.05$), suggesting that the majority of simulated estimates fail to reach the 5% statistical significance level. As shown in Figure A1b, the vertical dashed line represents the baseline regression coefficient (0.0458) of the impact of LFC on RDE. All simulated coefficients are distributed on the left side of the baseline estimate with a mean value close to zero, confirming that the core findings are not driven by random chance and passing the placebo test.

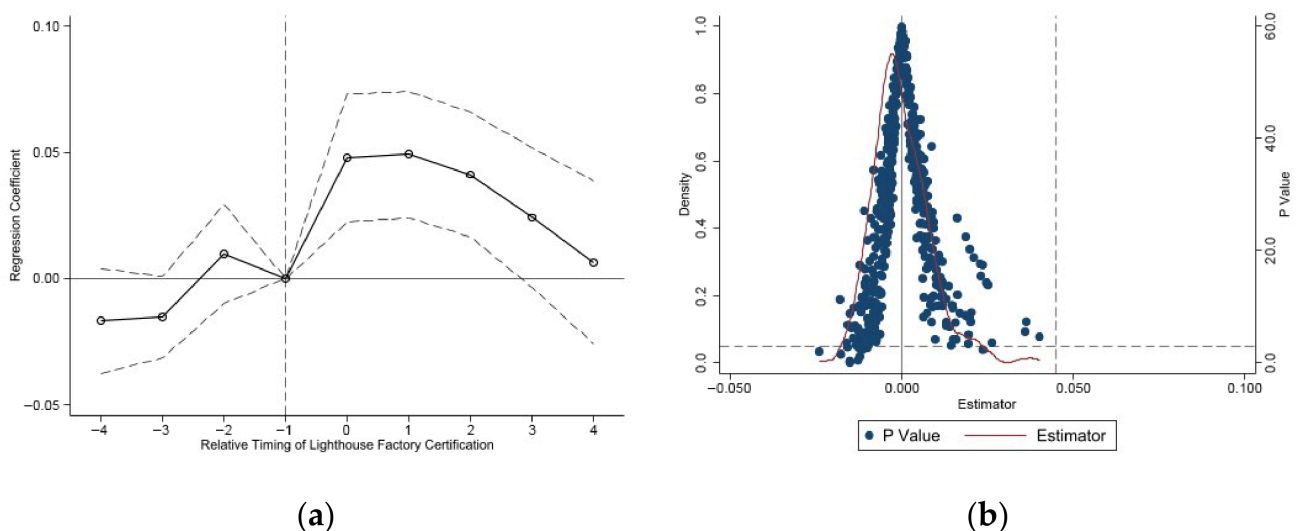


Figure A1. (a) Parallel trend test; (b) placebo test. The black vertical dashed line in panel (a) denotes the year in which the policy shock occurred, while that in panel (b) denotes the baseline regression coefficient.

(3) Bacon Decomposition

The decomposition results of the average treatment effect on the treated (ATT) reveal that the vast majority of identification information (with a weight of 0.973) originates from the comparison between treatment groups and never-treated groups. Meanwhile, the DID estimates derived from different comparison groups are highly consistent in magnitude. These findings further demonstrate that the baseline DID estimation results are robust and reliable.

(4) PSM-DID Method

To alleviate sample selection bias, this paper employs the PSM-DID method for robustness testing. Model 1 to Model 3 in Table A2 adopt three classic matching strategies, including 1:1 nearest neighbor matching without replacement, kernel matching, and radius matching, to re-estimate the benchmark model.

(5) Stacked DID Method

To eliminate estimation bias caused by heterogeneous treatment effects across different periods, this paper applies the stacked DID model in Model 4 to re-evaluate the impact of LFC on RDE.

(6) Exclusion of Other Policy Interferences

To rule out the confounding effects of other digital economy policies, this paper incorporates the interaction terms of treatment and post-period variables corresponding to the Big Data Industry Development Demonstration Project and Digital Industry Cluster Policy as control variables in Model 5. This approach effectively eliminates the interference of alternative industrial policies on the empirical results.

(7) Exclusion of Megacity Samples

Megacities possess unique resource endowments and development paradigms that may interfere with the baseline estimation. To avoid such peculiar interference and ensure the universality and generalizability of the research conclusions, all megacity samples are excluded from the empirical analysis in Model 6.

(8) Elimination of Samples Affected by Spatial Spillover Effects

Although the baseline analysis adopts prefecture-level city data to mitigate the spatial spillover interference among adjacent cities, the long-distance spillover effects generated by technological linkages between cities are not fully eliminated. To address this issue, this paper further excludes, in Models 7, 8, and 9 in Table A3, core city samples in digital technology transfer networks, digital technology cooperation networks, and digital knowledge spillover networks.

(9) Alternative Measures of the Dependent Variable

To ensure that the findings are not sensitive to the specific measurement approach of the dependent variable, the model is re-estimated using two alternative measures: the natural logarithm of the number of new digital-economy firms, and the share of new digital-economy firm registrations in total new firm registrations. The results remain robust, as shown in Models 10 and 11, confirming the reliability of the core conclusions.

Table A2. Robustness test results.

	(1) RDE	(2) RDE	(3) RDE	(4) RDE	(5) RDE	(6) RDE
LFC	0.0194 ** (0.0083)	0.0461 *** (0.0108)	0.0463 *** (0.0109)		0.0423 *** (0.0118)	0.0577 *** (0.0138)
Post0_4				0.0337 ** (0.0144)		
Control	Y	Y	Y	Y	Y	Y
City Fe	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Constant	0.9505 *** (0.2592)	2.6590 *** (0.5898)	2.6595 *** (0.5899)	2.7901 *** (0.6748)	2.6728 *** (0.5881)	2.7356 *** (0.6045)
Observations	3085	20,728	20,716	475,967	20,732	20,127
R2	0.7279	0.5007	0.5007	0.4766	0.5009	0.4990

Note: *** $p < 0.01$, ** $p < 0.05$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

Table A3. Robustness test results.

	(7) RDE	(8) RDE	(9) RDE	(10) RDE	(11) RDE
LFC	0.0584 *** (0.0223)	0.0786 *** (0.0300)	0.0428 *** (0.0110)	0.1383 *** (0.0196)	0.0165 *** (0.0036)
Control	Y	Y	Y	Y	Y
City Fe	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Constant	2.5703 *** (0.8391)	2.2821 ** (1.0890)	2.0872 *** (0.5017)	7.3672 *** (0.1721)	0.3806 *** (0.0297)
Observations	14,554	12,915	20,285	20,735	20,735
R2	0.6080	0.6756	0.4825	0.9011	0.6148

Note: *** $p < 0.01$, ** $p < 0.05$. Robust standard error in brackets. Y indicates that both fixed effects and control variables are controlled for in the specification.

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