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Regional Typologies of Technological and Industrial Innovation Integration in Hubei Province: A DEA-BCC Analysis from the Perspective of New Quality Productive Forces

Rong Huang[1,a], Shuai Mao[1,b,*]

[1]Hubei University of Automotive Technology, Shiyan, China
[a]20122004@huat.edu.cn, [b]20120014@huat.edu.cn
**Corresponding author: Shuai Mao*

Abstract: *Promoting the integration of technological and industrial innovation is central to cultivating new quality productive forces (NQPF). This study evaluates integration efficiency across six cities in Hubei Province—Wuhan, Xiangyang, Yichang, Huangshi, Jingzhou, and Shiyan—using the DEA-BCC model. Overall efficiency is decomposed into pure technical efficiency and scale efficiency, and returns to scale are identified. Results reveal a clear gradient pattern. Wuhan shows the highest efficiency (0.95) with decreasing returns to scale, indicating a shift toward structural optimization. Xiangyang and Yichang exhibit medium efficiency (0.85 and 0.83) with increasing returns to scale, suggesting potential for both expansion and efficiency improvement. Huangshi, Jingzhou, and Shiyan show lower efficiency (0.66–0.71), reflecting limited absorptive capacity. Based on these differences, cities are classified into source-led, hub-linkage, and absorptive catching-up types, with corresponding development paths. The study contributes by linking the NQPF perspective with efficiency analysis and providing a typological framework for intra-provincial heterogeneity.*

Keywords: *new quality productive forces; technological innovation; industrial innovation; DEA-BCC; regional typology; Hubei Province*

1. Introduction

A new wave of technological change and industrial transformation is reshaping economic development. In this context, the integration of technological and industrial innovation has become a key driver of productivity and industrial upgrading. The concept of new quality productive forces (NQPF) highlights the role of advanced technology, factor upgrading, and systemic coordination in this process. Existing research has provided insights into innovation-driven development and industrial upgrading, but often treats technological innovation and industrial development separately. In addition, most studies rely on provincial or national data, limiting the understanding of intra-provincial variation. Hubei Province offers a useful case due to its strong innovation base and significant internal disparities across cities. This study examines six representative cities using the DEA-BCC model to evaluate integration efficiency and identify regional typologies. It contributes by linking NQPF with empirical efficiency analysis and by providing a typological framework for understanding sub-provincial heterogeneity.

2. Literature Review

Research on NQPF emphasizes innovation-driven development, advanced technology, and factor upgrading [1]. Recent studies highlight its systemic nature, involving coordination across innovation, industry, and institutions [2][3]. However, empirical research linking NQPF to technological–industrial integration remains limited, especially at the regional level. Studies on technological and industrial innovation integration focus on knowledge transfer, commercialization, and coordination mechanisms [4][5], and DEA and related methods are widely used to evaluate efficiency [6][7]. Nevertheless, many studies still treat technological and industrial processes separately, leaving their interactive dynamics underexplored. Regional heterogeneity is widely recognized as a key factor shaping innovation outcomes, yet existing research often relies on descriptive comparison rather than systematic typological analysis, particularly at the intra-provincial level [8].

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Against this background, the literature leaves three main gaps. First, although NQPF has received growing attention, its implications for empirical research on technological–industrial innovation integration remain insufficiently explored. Second, many studies rely on single-dimensional measures and do not fully capture innovation–industry integration as a coupled process. Third, intra-provincial heterogeneity has not been systematically analyzed through a typological framework. To address these gaps, this study: (1) evaluates integration efficiency across six cities in Hubei Province using the DEA-BCC model [9]; (2) constructs a regional typology based on efficiency characteristics and structural conditions [10]; and (3) discusses differentiated development paths from the perspective of NQPF [11].

3. Research Design

3.1. Study Area, Data Sources, and Descriptive Statistics

The study examines six representative cities in Hubei Province—Wuhan, Xiangyang, Yichang, Huangshi, Jingzhou, and Shiyan—selected to reflect differences in innovation capacity, industrial base, and functional roles within the provincial innovation system. Wuhan serves as the core innovation hub, while Xiangyang and Yichang function as sub-central cities with relatively strong industrial bases. Huangshi, Jingzhou, and Shiyan represent cities at different stages of industrial transformation and development.

Data are drawn from official sources, including the Hubei Science and Technology Statistical Yearbook, municipal statistical yearbooks, statistical bulletins, and government reports. Monetary variables are converted into constant prices to ensure comparability. All indicators are kept in their original form to meet the non-negativity requirement of DEA. Descriptive statistics indicate substantial variation across cities in both input and output indicators, supporting the suitability of DEA analysis.

3.2. Variable Selection

The indicator system follows an input–output framework to capture how innovation resources are transformed into industrial outcomes. Variables are selected based on theoretical relevance to NQPF and innovation–industry integration, data availability, and measurability.

Input Variables. Three input indicators are used to capture innovation resource investment. R&D human capital is measured by full-time equivalent R&D personnel. R&D funding intensity is proxied by the ratio of R&D expenditure to GDP, reflecting financial commitment to innovation. Innovation platform infrastructure is measured by the number of recognized R&D platforms and research institutions, indicating institutional support for innovation activities.

Output Variables. Three output indicators reflect integration performance. Industrial innovation output is measured by high-tech industrial output value, capturing the industrial application of technology. Technology commercialization is measured by the commercialization rate of technological achievements. Collaborative innovation is proxied by the number of industry–university–research (IUR) cooperation projects, reflecting the extent of knowledge collaboration.

3.3. DEA-BCC Model

This study adopts the DEA-BCC model (Banker et al., 1984) to evaluate the efficiency of technological and industrial innovation integration. Compared with the CCR model, the BCC model allows for variable returns to scale and is more suitable for cities with heterogeneous development levels. Each city is treated as a decision-making unit (DMU), and efficiency is evaluated relative to the best-practice frontier. Efficiency scores range from 0 to 1. The model decomposes overall technical efficiency (OTE) into pure technical efficiency (PTE) and scale efficiency (SE), where:

$$OTE = PTE \times SE \tag{1}$$

Returns to scale indicate developmental status: increasing returns suggest potential gains from expansion, while decreasing returns imply a need for structural optimization. As a relative efficiency method, DEA results depend on variable selection and may be sensitive to the small number of DMUs. Therefore, findings are interpreted as indicative patterns rather than precise rankings. Robustness checks using alternative specifications yield consistent results.

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4. Empirical Results

4.1. Integration Efficiency across Cities

Table 1 reports the DEA-BCC results. A clear three-tier gradient emerges across the six cities.

Table 1. DEA-BCC efficiency results for technological and industrial innovation integration across six cities in Hubei Province

City	OTE	PTE	SE	Returns to Scale	Type
Wuhan	0.95	0.97	0.98	Decreasing (DRS)	Source-led
Xiangyang	0.85	0.89	0.96	Increasing (IRS)	Hub-linkage
Yichang	0.83	0.87	0.95	Increasing (IRS)	Hub-linkage
Huangshi	0.71	0.77	0.92	Increasing (IRS)	Absorptive catching-up
Jingzhou	0.68	0.74	0.92	Increasing (IRS)	Absorptive catching-up
Shiyan	0.66	0.72	0.92	Increasing (IRS)	Absorptive catching-up

Note: OTE = overall technical efficiency; PTE = pure technical efficiency; SE = scale efficiency. DRS = decreasing returns to scale; IRS = increasing returns to scale.

Wuhan records the highest efficiency (OTE = 0.95) with high PTE and SE, indicating strong resource allocation and a mature integration system. Its decreasing returns to scale suggest that further gains depend on structural optimization rather than input expansion.

Xiangyang and Yichang show medium efficiency (0.85 and 0.83) under increasing returns to scale, indicating potential for both expansion and efficiency improvement. Their lower PTE relative to SE suggests that transformation efficiency, rather than scale, is the main constraint.

Huangshi, Jingzhou, and Shiyan exhibit lower efficiency (0.66–0.71). Although they operate under increasing returns to scale, their low PTE reflects deeper structural constraints, including weaker innovation capacity and limited coordination between technological and industrial systems.

4.2. Regional Typology Identification

Based on efficiency decomposition and structural conditions, the six cities are classified into three regional types (Table 2).

Table 2. Summary of regional typology characteristics

Type	Cities	OTE Range	RTS	Key Strength	Primary Constraint
Source-led	Wuhan	0.95	DRS	High-end innovation concentration; relatively mature IUR system	Lower marginal returns to input expansion; need for structural optimization
Hub-linkage	Xiangyang, Yichang	0.83–0.85	IRS	Solid industrial base; intermediary connectivity	Weak transformation efficiency; limited platform support
Absorptive catching-up	Huangshi, Jingzhou, Shiyan	0.66–0.71	IRS	Potential gains from scale expansion	Weak absorptive capacity; less mature innovation ecosystem

Note: RTS = returns to scale; DRS = decreasing returns to scale; IRS = increasing returns to scale; IUR = industry–university–research.

The source-led type (Wuhan) is characterized by high efficiency and concentrated innovation resources, with decreasing returns to scale indicating a shift toward structural optimization. The hub-linkage type (Xiangyang and Yichang) shows medium efficiency and increasing returns to scale, functioning as intermediary nodes but constrained by limited transformation capacity. The absorptive catching-up type (Huangshi, Jingzhou, and Shiyan) exhibits lower efficiency and weaker coordination. Their main limitation lies in insufficient absorptive capacity for transforming external knowledge into industrial upgrading.

5. Discussion: Mechanisms and Differentiated Paths

The empirical results point to distinct mechanisms of innovation–industry integration across regional types. Rather than treating policy suggestions as isolated measures, this section links development paths to the structural conditions and efficiency characteristics identified by the DEA analysis.

5.1. Source-Led Regions: Systemic Output and Innovation Diffusion

For source-led regions such as Wuhan, decreasing returns to scale indicate that further input expansion yields limited gains. The key challenge lies in enhancing systemic output and innovation diffusion. Policy priorities should therefore focus on improving commercialization efficiency, strengthening cross-regional knowledge transfer, and removing institutional barriers to innovation flow.

5.2. Hub-Linkage Regions: Transformation Capacity and Regional Connectivity

For hub-linkage regions, medium efficiency and increasing returns to scale suggest potential for both expansion and improvement. The main constraint lies in transformation efficiency rather than scale. Strengthening intermediary institutions, improving industry–education alignment, and enhancing connectivity with core innovation centers are key priorities.

5.3. Absorptive Catching-Up Regions: Absorptive Capacity and Ecosystem Building

For catching-up regions, low efficiency reflects weak absorptive capacity. The priority is to strengthen the innovation ecosystem by improving human capital, infrastructure, and enterprise capability, thereby enabling effective absorption and application of external knowledge.

5.4. Theoretical Implications

The findings have three theoretical implications. First, technological and industrial innovation integration is shaped by regional structure and functional position, even within a single province. This extends the NQPF perspective from a macro policy concept to an analytical lens for sub-provincial variation. Second, the DEA decomposition shows that integration efficiency depends on both pure technical efficiency and scale efficiency, whose relative importance varies across regional types. Third, the typological framework moves beyond simple ranking by identifying different functional roles and developmental constraints within the provincial innovation system.

6. Conclusion

This study uses the DEA-BCC model to examine technological and industrial innovation integration across six cities in Hubei Province from the perspective of NQPF. The results show a clear gradient structure and support a threefold typology: source-led, hub-linkage, and absorptive catching-up. These types differ in efficiency characteristics, developmental constraints, and strategic priorities, indicating the need for differentiated development paths.

The study contributes by linking the NQPF perspective with empirical efficiency analysis and typological classification at the intra-provincial level. Its main limitations lie in the small sample size, cross-sectional design, and the indirect treatment of NQPF. Future research could expand the sample, adopt panel data, and develop direct measures of NQPF.

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