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Digital Governance and the Regional Pooling Efficiency of Pension Insurance: A Four-Dimensional Collaborative Analysis Based on Yingkou City

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Abstract

Using Liaoning's 13 prefecture-level cities during 2015–2024 as the comparative background and Yingkou City as the focal case, this paper examines how digital governance and collaborative institutional arrangements shape the regional pooling efficiency of China's basic pension insurance. Building on the dynamic-balance view of efficiency, the paper combines efficiency decomposition, benchmark Tobit evidence, and mechanism analysis to distinguish scale-matching problems from process-efficiency bottlenecks. The results indicate that Yingkou's mean technical efficiency (TE) is 0.66, with pure technical efficiency (PTE) at 0.60 and scale efficiency (SE) at 0.89, showing that the core weakness lies primarily in process inefficiency rather than in scale mismatch. In the benchmark regression, institutional closure (0.142), economic fundamentals (0.098), digital governance (0.067), and the post-2022 reform window (0.041) are positively associated with pooling efficiency, whereas demographic pressure (-0.121) and fiscal stress (-0.054) are negatively associated with it. More importantly, the interaction term between institutions and technology (0.073) is significantly positive, implying that digital tools improve efficiency most effectively when rules, standards, and accountability are embedded into operational processes. On this basis, the paper proposes a four-dimensional collaborative path of policy adaptation, resource integration, technology enablement, and regulatory assurance, together with a staged roadmap oriented toward PTE improvement. The study provides an analytically grounded article-style condensation of the dissertation evidence and offers a practical reference for transformation-oriented cities facing ageing pressure, fiscal constraints, and digital-transition tasks.

Keywords

Digital governance; pension insurance; regional pooling efficiency; Yingkou City; panel Tobit; four-dimensional collaborative mechanism.

1. Introduction

1.1. Research background and significance

With the progressive advancement of national pooling and the convergence of provincial pooling rules in China, the key challenge of pension insurance reform is no longer confined to how to raise the formal pooling level. It increasingly concerns whether local pooling units can translate unified institutional requirements into efficient, stable, and equitable implementation outcomes. Under this policy background, regional differences in pension insurance performance are shifting from disparities in institutional design to disparities in governance quality, process coordination, and digital implementation capacity. Yingkou City, located in Liaoning Province, is a particularly suitable case for observation because it combines the features of an old industrial-base city, a port economy, demographic pressure, and a visible need for administrative transformation.

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This paper follows the dynamic-balance view of efficiency. In this perspective, pooling efficiency is not equivalent to cutting expenditure or maximizing book surpluses. Rather, it refers to the capacity of a regional pooling unit to coordinate cost control, benefit protection, and long-term sustainability under unified institutional boundaries. Once efficiency is understood in this way, digital governance cannot be reduced to the construction of platforms alone. Its real significance lies in whether it lowers friction costs, reduces repeated verification, stabilizes benefit administration, and improves the conversion of existing administrative resources into effective outputs.

1.2. Research gap and article focus

Existing studies on pension insurance have accumulated important discussions on national pooling, provincial adjustment, fiscal sustainability, and institutional equity [1-5]. However, three gaps remain visible at the municipal level. First, many studies emphasize efficiency measurement but provide insufficient explanation of how efficiency gaps emerge in operational processes. Second, although digital transformation is frequently discussed in policy documents, empirical research still lacks a sufficiently systematic framework for connecting digital governance with process efficiency, cross-departmental collaboration, and risk control [6-8]. Third, mechanism-oriented evidence grounded in a specific city context remains limited, especially for transformation-oriented cities that face simultaneous ageing pressure, fiscal constraints, and administrative modernization tasks.

To address these gaps, this paper narrows the analytical focus to the role of digital governance in improving regional pooling efficiency in Yingkou. Instead of repeating a broad efficiency-comparison narrative, the article extracts one central problem from the dissertation: if Yingkou's main shortcoming lies in PTE rather than SE, then what does digital governance actually improve, under what conditions does it work, and how should its implementation sequence be arranged?

1.3. Research content and methods

This paper is organized around three linked tasks. First, it identifies the basic efficiency facts of Yingkou by using the annual efficiency scores and efficiency decomposition reported in the dissertation. Second, it extracts the benchmark regression evidence to show the direction and relative magnitude of the variables associated with efficiency. Third, it translates the empirical results into a governance framework and proposes a PTE-oriented improvement path based on the four-dimensional collaborative mechanism of policy adaptation, resource integration, technology enablement, and regulatory assurance.

Methodologically, the article relies on a comparative city sample covering Liaoning's 13 prefecture-level cities from 2015 to 2024. The efficiency evidence is derived from SBM-DEA decomposition, and the factor-identification evidence is based on a benchmark panel Tobit model suitable for efficiency scores bounded between 0 and 1. The article itself is written as a condensed journal-style output extracted from the dissertation rather than as a full methodological reconstruction.

2. Theoretical basis of digital governance and pooling efficiency

2.1. The dynamic-balance view of efficiency

The dynamic-balance view of efficiency emphasizes that pension insurance is a typical public institutional arrangement with multiple objectives. Its performance cannot be judged by a single output such as fund balance, administrative speed, or service volume. Instead, efficiency must be understood as a relative coordination among three dimensions. The first is cost control, meaning that institutional operation should reduce unnecessary administrative friction and resource waste. The second is benefit protection, meaning that the system should preserve the

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timeliness, accessibility, and consistency of benefit delivery. The third is long-term sustainability, meaning that the system should remain resilient under population ageing, fiscal stress, and policy adjustment [9-11].

This theoretical position is especially important for digital governance research. If digitalization is evaluated only by online volume or platform quantity, it may produce superficial conclusions. A system may appear modern on the surface while still generating repeated submission of materials, online–offline layering, and heavy manual fallback in practice. Therefore, digital governance should be assessed by whether it improves process performance indicators such as one-stop completion, automatic verification, returned-case reduction, and closed-loop risk handling.

2.2. Mechanisms of digital governance

Digital governance affects regional pooling efficiency through at least four process-oriented mechanisms. First, it can reduce transaction costs by replacing repeated offline procedures with online declaration, electronic materials, and intelligent routing. Second, it can improve coordination efficiency by enabling data sharing among human-resources and social-security departments, taxation, public security, civil affairs, and related administrative actors. Third, it can strengthen service accessibility by reducing the dependence of service delivery on time, distance, and manual document transfer. Fourth, it can enhance risk regulation through abnormal-case identification, eligibility verification, and traceable correction chains [4,6,7,12].

However, the release of these gains depends on whether digital tools are matched with institutional standards and organizational capacity. When technology is introduced without process reengineering, legacy frictions are often migrated online. When data are connected without standardized fields and rule lists, automatic verification remains superficial. In this sense, digital governance is not an independent variable that works in isolation; it requires institutional closure, resource carrying capacity, and regulatory embedding.

2.3. The four-dimensional collaborative mechanism

To explain why some digital tools generate stable efficiency gains while others do not, this paper adopts the four-dimensional collaborative mechanism proposed in the dissertation. Policy adaptation defines executable standards and clarifies local implementation boundaries under unified provincial rules. Resource integration provides the carrying foundation through funding support, staffing, interface coordination, and organizational alignment. Technology enablement improves process efficiency through online substitution, back-office parallel verification, and rule embedding into systems. Regulatory assurance maintains stability by incorporating risk warning, audit logic, abnormal-case disposal, and accountability tracing into the operational chain.

These four dimensions should not be treated as parallel slogans. Their internal sequence matters. Policy adaptation comes first because unclear standards lead directly to repeated review. Resource integration follows because even well-designed rules fail if no staffing, data interface, or funding support is available. Technology enablement becomes effective only after the previous two conditions are reasonably satisfied. Regulatory assurance closes the loop by preventing short-term speed gains from producing long-term correction costs. This logic is summarized in Figure 3.

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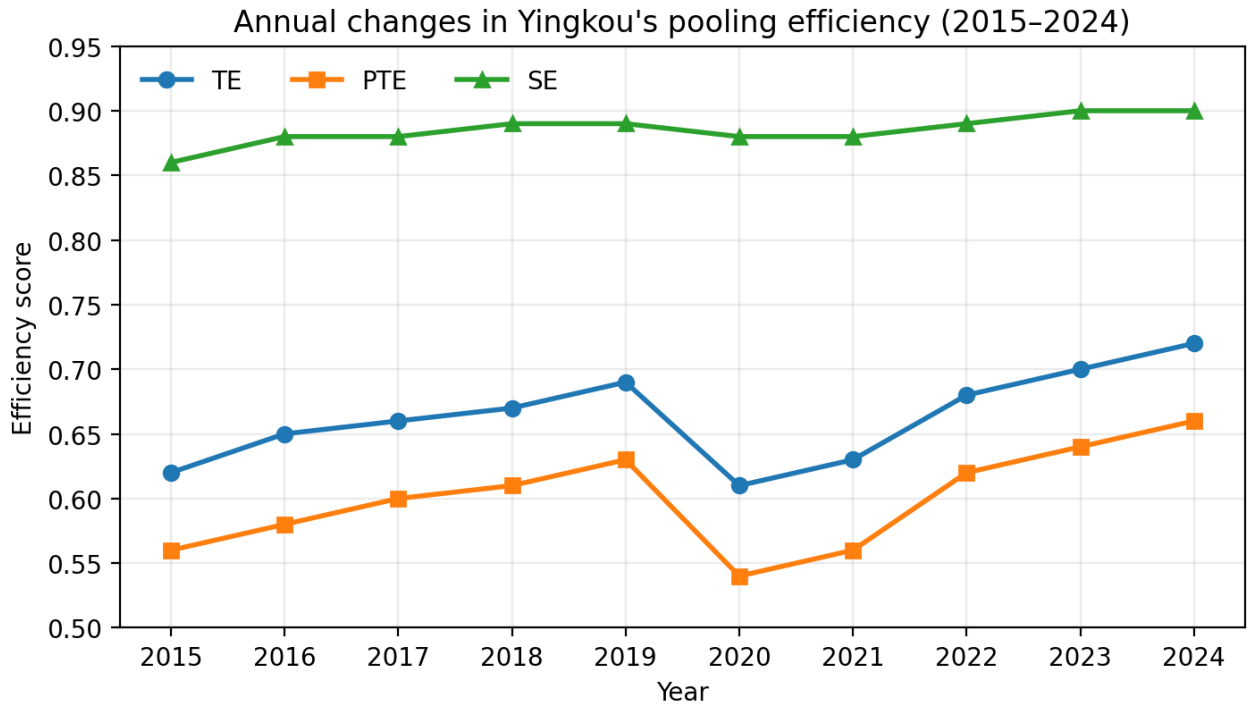

Figure 1 Annual changes in Yingkou's TE, PTE, and SE (2015–2024)

3. Empirical evidence from Yingkou City

3.1. A PTE-centered efficiency fact

The efficiency decomposition of Yingkou shows why process efficiency should be placed at the center of governance design. During 2015–2024, Yingkou's mean TE is 0.66, its mean PTE is 0.60, and its mean SE is 0.89. The relatively high SE indicates that scale mismatch is not the principal problem. By contrast, the lower PTE indicates that the main shortcoming lies in the conversion of existing inputs into effective outputs. This conclusion is reinforced by annual data. In 2020, TE dropped to 0.61 and PTE to 0.54, while SE remained at 0.88. The shock was therefore transmitted mainly through process congestion, verification burden, and implementation frictions rather than through a structural collapse in scale matching.

This distinction is analytically important. If the core bottleneck is wrongly interpreted as a scale problem, policy recommendations may overemphasize additional inputs or broad institutional expansion. Yet the evidence suggests that the first-order problem in Yingkou is how to reduce repeated verification, improve standards consistency, and make cross-departmental circulation more stable. In other words, the city needs better process capacity before it needs more scale.

3.2. Benchmark regression results

The benchmark panel Tobit results further clarify the factors associated with efficiency differences. Institutional closure and economic foundations are significantly positive, while demographic pressure and fiscal stress are significantly negative. Digital governance remains positively associated with efficiency after controlling for the other variables, and the post-2022 policy window also shows an upward association. Most notably, the interaction term between institutions and technology is significantly positive, indicating that digital governance is most effective when rules and technical systems reinforce each other.

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Table 1 Benchmark panel Tobit results for pooling efficiency (dependent variable: TE)

Variable	Coefficient	Std. Error	Interpretive point
Inst	0.142	(0.032)	Institutional closure improves efficiency
Econ	0.098	(0.028)	Economic foundations strengthen output capacity
Pop	-0.121	(0.030)	Demographic pressure constrains efficiency
Tech	0.067	(0.029)	Digital governance reduces friction costs
Fiscal	-0.054	(0.026)	Fiscal stress raises mismatch risk
Post2022	0.041	(0.018)	The reform window is associated with improvement
Inst×Tech	0.073	(0.021)	Institution–technology synergy improves efficiency

The coefficients do not by themselves prove causality, but they are highly informative for mechanism design. The positive coefficient for Tech indicates that better online service capacity, data use, and digital handling are associated with higher efficiency. Yet the still larger coefficient for Inst and the significant interaction term Inst×Tech suggest that technology alone is not enough. Its gains become stronger when rule implementation is clearer, standard lists are embedded into the system, and accountability is traceable. This is precisely why the article treats digital governance as part of a broader collaborative mechanism rather than as a stand-alone remedy.

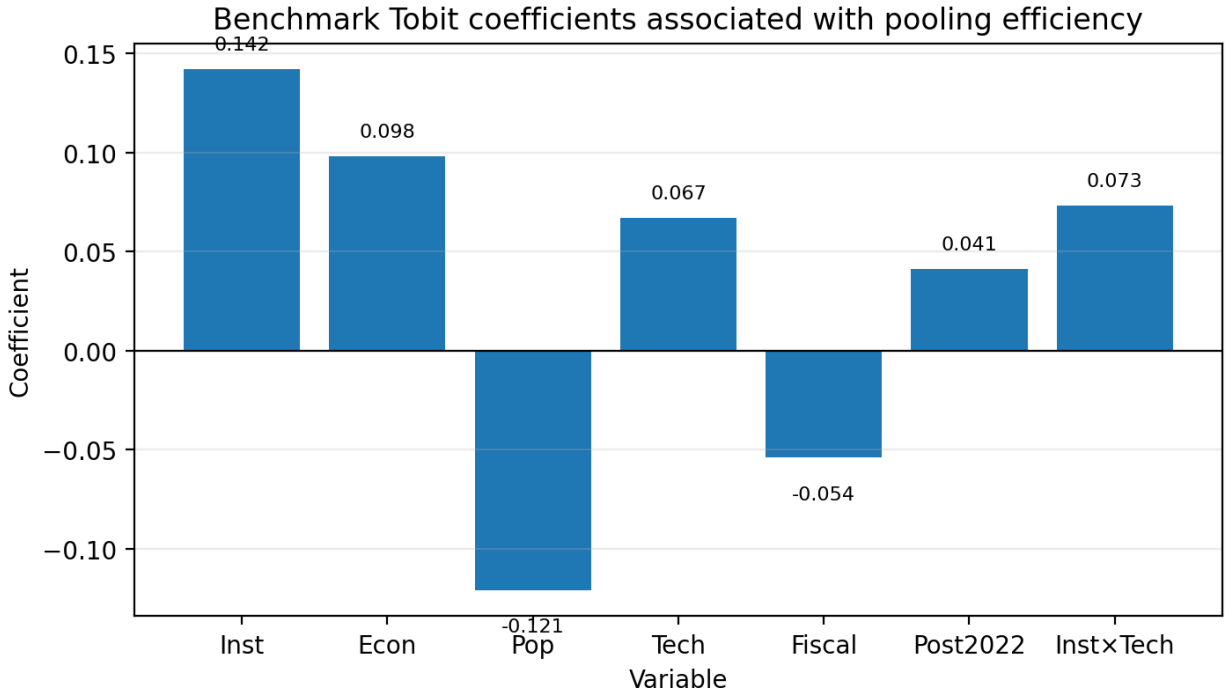

Figure 2 Benchmark coefficients associated with pooling efficiency

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3.3. Mechanism mapping and interpretation

A mechanism-based reading of the regression results yields a clearer governance logic. Institutional closure mainly affects PTE by reducing implementation deviations, inconsistent front-window standards, and returned-case processing. Digital governance mainly affects PTE by decreasing repeated submission, manual rechecking, and circulation delay. Their interaction term points to a higher-order effect: when rules are embedded into system logic, online handling no longer functions as a thin digital shell, but becomes a genuine process-reengineering tool. Economic development supports both PTE and SE by strengthening the resource base and organizational capacity. By contrast, demographic pressure and fiscal stress enlarge workload and compress resource flexibility, which aggravates congestion if process design remains unchanged.

The substantive implication is that Yingkou's efficiency problem should not be framed as a generalized deficit of resources. Existing inputs are not absolutely insufficient; the more critical weakness lies in how these inputs are transformed into service outputs, coordinated decisions, and controlled risks. Therefore, the central target of governance reform should be the conversion rate of existing resources rather than simply the expansion of resources.

Table 2 Mechanism mapping between empirical factors and governance dimensions

Influencing factor	Direction of result	Related mechanism dimension	Main object affected	Process-side explanation
Inst	Positive (0.142)	Policy adaptation / regulatory assurance	Mainly PTE	Consistent standards and traceable accountability reduce returned and reprocessed cases
Tech	Positive (0.067)	Technology enablement	Mainly PTE	Data sharing and online substitution reduce repeated material submission and manual verification
Inst×Tech	Positive (0.073)	Collaborative gain	Mainly PTE	Rules embedded in system logic support automatic verification and closed-loop circulation
Econ	Positive (0.098)	Resource integration	PTE / SE	A stronger economic base improves staffing, service capacity, and scale matching
Pop	Negative (-0.121)	Demand expansion / congestion	Mainly PTE	Higher workload and service complexity create process congestion
Fiscal	Negative (-0.054)	Resource constraint	PTE / SE	Patchwork governance becomes more likely under tight fiscal pressure

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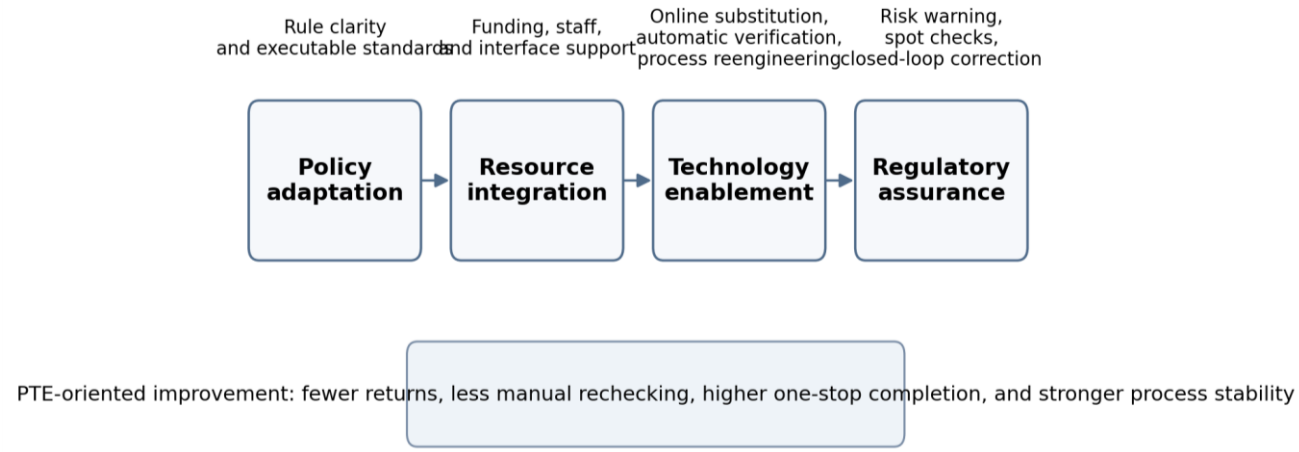

Figure 3 The four-dimensional collaborative mechanism for PTE-oriented improvement

4. Governance path design for Yingkou

4.1. Policy adaptation and resource integration

The first stage of improvement should begin with policy adaptation. For Yingkou, this means clarifying front-window standards, material lists, transfer-and-continuation rules, settlement criteria, and exceptional-case handling logic so that the same matter is processed according to the same standard across online and offline channels. Without this step, digital systems merely reproduce ambiguity in electronic form. The second task is resource integration. The city must align its staffing, training, and interface resources with the actual bottlenecks of high-frequency business chains instead of spreading efforts too thinly across non-critical links.

Resource integration also has a horizontal dimension. Pension insurance operation depends on interaction with taxation, public security, civil affairs, and other departments. If interface governance is weak, high-quality digital tools cannot generate real efficiency gains because the basic circulation of information remains unstable. Therefore, cross-departmental resource coordination should be judged not by formal agreements alone, but by whether it improves actual turnaround time, verification accuracy, and one-stop completion rates.

4.2. Technology enablement and regulatory assurance

Technology enablement should then focus on business chains that contribute most directly to PTE improvement. These typically include eligibility certification, contribution registration, benefit-related verification, abnormal-case identification, and parallel back-office checking. The immediate target is not platform expansion in a general sense, but the reduction of returned cases, manual rechecking, duplicated submission, and fragmented circulation. Electronic materials, e-signatures, unified identity recognition, and embedded rule engines become valuable only insofar as they compress these concrete sources of friction.

Regulatory assurance is indispensable because speed gains without risk discipline can produce delayed losses. Eligibility verification, abnormal-case disposal, consistency checks between business flow and fund flow, and closed-loop correction mechanisms should therefore be built into the process rather than appended after the fact. In practical terms, Yingkou should treat process monitoring, targeted spot checks, and risk profiling as part of digital governance itself, not as separate administrative burdens.

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4.3. A staged PTE-oriented roadmap

On the basis of the dissertation evidence, a staged roadmap can be proposed. In the short term, Yingkou should prioritize rule-list standardization, data docking for high-frequency matters, and the closed loop of benefit eligibility certification. In the medium term, it should promote process reengineering, back-office parallel verification, and the expansion of online substitution from simple services to more complex matters. In the longer term, it should form a stable integrated monitoring system linking efficiency indicators, process indicators, and risk indicators. This sequence reflects the logic of easy matters first and difficult matters later, with the direct objective of pushing PTE upward while keeping regulatory stability intact.

Table 3 Staged roadmap for PTE-oriented governance improvement in Yingkou

Stage	Main task	Key process indicators	Expected efficiency effect
Short term (0–6 months)	Standardize rule lists; close eligibility loop; finish priority data docking	Returned-case rate; auto-verification coverage; one-stop completion	Immediate PTE gains through lower friction
Medium term (6–18 months)	Reengineer high-frequency processes; expand parallel verification; deepen online handling	Online-substitution rate; handling time; manual rechecking share	More stable conversion and lower congestion cost
Long term (18+ months)	Integrate efficiency, process, and risk monitoring; institutionalize review-based iteration	Warning timeliness; abnormal-case cycle; PTE fluctuation convergence	Sustained improvement with stronger resilience

5. Discussion

5.1. Why process efficiency matters more than scale expansion

The empirical evidence suggests that Yingkou's path of improvement should begin with process efficiency rather than with expansionary scale strategies. A relatively high SE shows that the city is not primarily constrained by the inability to form a pooling scale. Its central weakness lies in the gap between available inputs and realized outputs. Therefore, efforts to increase governance resources will be inefficient if they are not accompanied by process redesign. This also explains why the interaction between institutions and technology is more analytically meaningful than the technology variable alone.

5.2. Avoiding superficial digitalization

A major risk in local governance reform is superficial digitalization. This occurs when online functions are added while paper logic, repeated verification, and fragmented responsibility remain unchanged. In such cases, digitalization increases visible complexity rather than reducing hidden friction. The paper therefore argues that evaluation should shift from construction indicators to process-performance indicators. Platform quantity, system access, and project investment are secondary; the more relevant measures are one-stop completion, returned-case reduction, automatic verification, and process stability.

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5.3. Broader implications

Although this article focuses on Yingkou, its analytical logic has wider relevance for transformation-oriented cities under unified pooling rules. Where demographic pressure, fiscal constraints, and administrative modernization coexist, regional pooling efficiency is unlikely to improve through a single-point breakthrough. It requires a coordinated chain in which rules, resources, technology, and regulation reinforce one another. In this sense, digital governance is most productive when it becomes an embedded component of institutional implementation rather than a separate modernization project.

6. Summary

This paper has reassembled the dissertation evidence into a journal-style analysis centered on digital governance. The main conclusion is straightforward: Yingkou's principal efficiency bottleneck lies in PTE, not in SE, which means that the city's first governance task is to improve process conversion rather than to expand scale mechanically. The benchmark evidence shows that institutional closure, economic foundations, and digital governance are positively associated with efficiency, whereas demographic pressure and fiscal stress are negatively associated with it. Most importantly, the significant positive interaction between institutions and technology indicates that digital tools are most effective when supported by clear rules, standardized interfaces, and embedded accountability.

On this basis, the article proposes a four-dimensional collaborative path of policy adaptation, resource integration, technology enablement, and regulatory assurance. Its practical implication is that the quality of digital governance should be judged by whether it reduces process friction, improves automatic verification, stabilizes service delivery, and lowers correction costs. For Yingkou and similar cities, improving pooling efficiency is therefore a matter not simply of building more systems, but of making rules, data, and responsibilities work together in a PTE-oriented sequence.

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