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DIGITAL TRADE POLICY AND URBAN INNOVATION CAPACITY: EVIDENCE FROM 280 CHINESE CITIES

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Abstract: With the evolution of the digital economy, digital trade policies have increasingly demonstrated significant effects on enhancing urban innovation capacity. This study combines policy qualitative analysis with quantitative research methodologies, utilizing the establishment of Cross-border E-commerce (CBEC) Comprehensive Pilot Areas as a quasi-natural experiment, based on data from 280 prefecture-level cities in China from 2010 to 2021, to examine the impact of digital trade policies on urban innovation capacity and its underlying mechanisms. The findings indicate that the establishment of CBEC pilot areas significantly enhanced urban innovation capacity, with particularly pronounced effects in China's eastern developed regions, tertiary industry-dominated cities, and megacities. Mechanism analysis reveals that establishing CBEC pilot areas enhances urban innovation capacity by improving digital infrastructure, facilitating service industry agglomeration, and optimizing the business environment.
Keywords: Digital trade policy; Cross-border E-commerce comprehensive pilot areas; Urban innovation capacity

1 INTRODUCTION

Urban innovation capacity has emerged as the cornerstone of economic transformation in the digital era, with cities serving as critical nodes for technological advancement and competitive advantage [1]. China's elevation of innovation-driven development to national strategic priority, exemplified by the 2024 Implementation Opinions on Promoting Future Industries Innovation, underscores the urgent need to understand policy mechanisms that enhance urban innovation capabilities. China's cross-border e-commerce growing 15.3% annually to 2.37 trillion yuan in 2023 creates natural experiments for policy evaluation.

The intersection of digital trade policy and urban innovation represents a rapidly evolving research frontier. Digital trade, defined as cross-border flows leveraging digital technologies with data as core production factor, has demonstrated significant capacity to drive industrial agglomeration and technological diffusion [2]. Cross-border e-commerce, as digital trade's most visible manifestation, has shown measurable impacts on corporate innovation through reduced transaction costs and enhanced market access [3-4].

Research shows marketization and capital investment drive innovation through resource optimization [5], while infrastructure investment exhibits non-linear effects on innovation efficiency [6]. The digital economy literature further demonstrates that smart city initiatives and digital infrastructure create platforms concentrating innovation resources [7-8], with digital technologies facilitating industrial structure optimization and productivity enhancement [9].

Despite these advances, three critical gaps persist. First, existing studies predominantly employ theoretical analyses or case studies, lacking rigorous empirical investigation of digital trade policies' causal impact on urban innovation capacity [10]. Second, while research documents cross-border e-commerce's macroeconomic effects, the specific mechanisms through which digital trade policies influence urban innovation processes remain underexplored, particularly regarding policy instrument-innovation pathway relationship[11]. Third, limited attention addresses the correspondence between policy design content and actual innovation outcomes, constraining deeper understanding of policy logic-implementation effectiveness relationships.

This study addresses a fundamental question: Do digital trade policies enhance urban innovation capacity, and through what mechanisms do these effects operate? We hypothesize that Cross-border E-commerce (CBEC) Comprehensive Pilot Areas, as China's flagship digital trade policy innovation, promote urban innovation through three complementary mechanisms derived from endogenous growth theory [12]: digital infrastructure development (reducing information costs and enhancing knowledge application efficiency), service industry agglomeration (generating knowledge spillovers and scale economies), and business environment optimization (reducing institutional transaction costs and innovation uncertainties).

We examine this relationship using a quasi-natural experiment design leveraging China's staggered establishment of 105 CBEC pilot areas across 280 cities (2010-2021). Our empirical strategy employs multi-period difference-in-differences analysis, enhanced by propensity score matching and extensive robustness checks. We integrate qualitative policy text analysis of 64 policy documents with quantitative mechanism testing, providing novel evidence on policy transmission channels. The study reveals that CBEC pilot areas significantly enhance urban innovation capacity (average treatment effect: 0.69%-1.52%), with pronounced heterogeneity across regions, industrial structures, and city scales. Eastern regions, service-oriented cities, and megacities exhibit stronger policy responsiveness, reflecting differential absorption capacities for digital trade innovations.

Our findings advance theoretical understanding by demonstrating how institutional innovation promotes endogenous growth through optimized resource allocation and reduced transaction costs. We provide the first comprehensive empirical evidence linking digital trade policy to urban innovation outcomes, identifying specific transmission mechanisms validated through systematic policy text analysis and mediation testing. The results offer practical guidance for policy optimization, suggesting differentiated approaches based on regional characteristics and industrial structures, while highlighting the importance of synergistic development across digital infrastructure, service agglomeration, and institutional environments.

2 MECHANISM AND RESEARCH ASSUMPTIONS

2.1 Qualitative Textual Analysis of Digital Trade Policies

Institutional reforms influence economic development and innovation dynamics by shaping the behavior of market participants. As an emerging institutional arrangement, digital trade policies' specific content and implementation trajectory directly determine their efficacy in influencing urban innovation capacity. This section employs thematic analysis methodology to systematically review and extract word frequencies from national policy documents related to CBEC pilot areas issued between 2010 and 2024.

Table 1 Summary of Policies Related to CBEC Pilot Areas (2010-2024)

No.	Year	Issuing Authority	Document Title
1	2015	The State Council	Reply on the Approval to Establish China (Hangzhou) CBEC Pilot Area
2	2019	State Taxation Administration	Announcement on Issues Concerning Deemed Taxation of Enterprise Income Tax for Retail Export Enterprises in CBEC Pilot Areas
3	2021	Ministry of Commerce et al.	Notice on Expanding the Pilot Program for CBEC Retail Imports and Strictly Implementing Regulatory Requirements
...	...	...	...
64	2024	General Administration of Customs	Announcement on Further Promoting the Development of CBEC Exports

Table 1 presents the 64 CBEC pilot area-related policy documents we systematically collected, spanning from 2015 when the first pilot area was established to 2024's latest policy releases, covering multiple departments including the State Council, Ministry of Commerce, and General Administration of Customs. This provides a comprehensive policy text foundation for subsequent qualitative analysis. Policy text analysis results show that digital trade policy frameworks primarily focus on three core themes: digital infrastructure development (3.55%), service industry agglomeration (4.85%), and business environment optimization (2.57%).

Table 2 Qualitative Analysis Results of Policy Texts

Theme	Related Keywords	Theme Frequency
Digital Infrastructure	Electronic, payment, information, platform, data, network, technology, system, digitalization, cloud computing, logistics informatization, blockchain, API integration, smart terminals, cybersecurity	3.55%
Service Industry Agglomeration	Service, business, enterprise, institution, operation, commodity, collaboration, cluster, warehousing, logistics, supply chain, finance, marketing, consulting, training, innovation cooperation, brand, cross-border service ecosystem	4.85%
Business Environment	Customs, regulation, legislation, pilot programs, declaration policy, taxation, compliance, intellectual property, risk prevention and control, administrative licensing, standardization, trade facilitation, dispute resolution, local policy support	2.57%

Table 2 reveals policy priorities in promoting urban innovation: service industry agglomeration receives strongest emphasis (4.85%), followed by digital infrastructure (3.55%), while business environment optimization (2.57%) provides essential institutional support, reflecting policymakers' strategic focus on ecosystem development, technological enablement, and institutional foundations.

2.2 Research Hypotheses

Building on Romer's endogenous growth theory [12], we theorize how the three identified mechanisms enable CBEC pilot areas to enhance urban innovation capacity. Digital infrastructure development reduces information acquisition costs and enhances knowledge application efficiency. Service industry agglomeration increases R&D talent concentration and generates knowledge spillovers. Business environment optimization reduces institutional transaction costs and facilitates technology adoption. These complementary mechanisms promote sustainable innovation-driven growth by improving resource allocation efficiency and accelerating knowledge diffusion. To formalize this theoretical framework, we construct an endogenous growth model that captures how these mechanisms influence key parameters affecting urban innovation capacity.

2.2.1 Basic model

We model a representative city with final product and knowledge product sectors. The final product Y represents urban economic output produced through a technology that depends on various knowledge products as intermediate inputs:

$$Y=\left(\int_0^N \tilde{x}_i^{\alpha}\, di\right)^{\frac{1}{\alpha}} \tag{1}$$

Where $\tilde{x}_i$ represents the effective utilization of intermediate good i after accounting for transaction costs, α denotes the elasticity of substitution between intermediate products (determining their marginal contribution to final output), and N indicates the variety of available knowledge products.

2.2.2 Knowledge production and input

The dynamics of knowledge creation follow an R&D-driven process where both current research efforts and existing knowledge stock contribute to innovation:

$$\frac{dN}{dt}=\delta L_R^{\theta} N^{\phi} \tag{2}$$

Where L_R represents R&D labor input, δ captures baseline knowledge production efficiency, θ measures the elasticity of R&D input to knowledge creation ($0<\theta<1$, reflecting diminishing returns), and ϕ captures knowledge spillover effects from existing stock ($0<\phi<1$). The production of each intermediate good depends on the total knowledge stock:

$$\tilde{x}_i=\eta N^{\beta} \tag{3}$$

Where η represents production efficiency and $\beta>0$ indicates that accumulated knowledge enhances intermediate goods productivity.

2.2.3 Total output

Substituting the intermediate goods production function into the final output equation and integrating across all varieties：

$$Y=\left(\int_0^N \tilde{x}_i^{\alpha}\, di\right)^{\frac{1}{\alpha}} \tag{4}$$

$$Y=\left(\int_0^N \left(\eta N^{\beta}\right)^{\alpha} di\right)^{\frac{1}{\alpha}} \tag{5}$$

$$Y=\eta N^{\frac{\alpha\beta+1}{\alpha}} \tag{6}$$

The three identified mechanisms influence key model parameters through distinct economic channels. Digital infrastructure development reduces information acquisition and processing costs, enhancing knowledge application efficiency (affecting parameters β and α). Service industry agglomeration increases human capital input in R&D sectors (L_R) while facilitating knowledge spillovers (affecting ϕ). Business environment optimization reduces institutional transaction costs, enabling more effective transformation of knowledge into productive applications.

Based on the above analysis, we propose the following hypotheses:

H1: Digital trade policies, represented by the establishment of CBEC pilot areas, promote urban innovation capacity.

H2: The establishment of CBEC pilot areas promotes urban innovation capacity through three mechanisms: digital infrastructure development, service industry agglomeration, and business environment optimization.

3 MODEL, VARIABLES AND DATA

3.1 Variable Selection

3.1.1 Dependent variable

Urban Innovation Capacity Index (Inno) This study constructs an urban innovation capacity index based on the methodology from the 2017 China Urban and Industrial Innovation Power Report jointly released by Yicai Research Institute and Fudan University. We estimate patent values using authorized patent data and aggregate registered capital of newly established enterprises, applying normalization and outlier removal procedures.

3.1.2 Core explanatory variable

The CBEC pilot area cities (CBEC) variable is constructed as an interaction term between Treat and Ryear, where Treat equals 1 for pilot cities and 0 for non-pilot cities.

3.1.3 Control variables

Through systematic review of policy documents related to CBEC pilot areas, 105 pilot areas had been established nationwide by 2021. This study selected 98 prefecture-level cities, and, building on research, identified key factors potentially influencing the establishment of CBEC pilot areas, incorporating them as control variables in the analytical framework. Specifically, the selected variables include: population scale level (Popu), human capital level (Capi), economic development level (Econ), infrastructure development level (Infra), government intervention degree (Gov), urbanization level (Urban), resident consumption level (Consum), and internet user level (Inter). Using these as control variables, we constructed a panel binary logit model to identify key factors influencing a city's designation as a CBEC pilot area. Cities selected as CBEC pilot areas were assigned a value of 1, and 0 otherwise, thus forming the core variable. Results indicate that CBEC pilot area establishment is primarily driven by seven antecedent factors: population scale, human capital level, economic development level, infrastructure development level, government intervention degree, urbanization level, and internet user level.

3.2 Data Sources

To conduct a comprehensive analysis, this study examines a sample of 280 Chinese cities over the period 2010-2021. Data regarding the establishment of CBEC pilot areas were primarily collected through systematic review of policy documents published by the State Council. Patent data were obtained from the China National Intellectual Property Administration. City-level data were sourced from the China City Statistical Yearbook and individual city statistical yearbooks.

3.3 Model Specification

This study analyzes 280 prefecture-level cities (including 105 CBEC pilot zones) using a multi-period DID approach to assess the policy's dynamic impact on urban innovation. The model specification follows:

$$Inno_{it}=\alpha_0+\alpha_1 cbec_{it}+\alpha_2 Control+\mu_i+v_t+\varepsilon_t \quad (7)$$

Where i denotes city and t denotes year. The dependent variable Inno represents urban innovation capacity; the core explanatory variable *cbec* represents CBEC pilot area cities; *Control* represents a series of city-level control variables, included to mitigate endogeneity concerns such as omitted variable bias; μ_i and v_t represent city and year fixed effects, respectively; and ε_t is the random disturbance term. This study primarily focuses on coefficient α_1, which captures the causal effect of CBEC pilot area policy on urban innovation capacity.

3.4 Descriptive Statistics

Descriptive statistical analysis results are presented in Table 3. The normalized mean value of urban innovation capacity is 0.0088, with maximum value of 1, indicating substantial variation across cities.

Table 3 Descriptive Statistics of Variables

Variables	Observations	Mean	Std. Dev	Minimum	Median	Maximum
Inno	3360	0.0088	0.3992	0.0000	0.0009	1
CBEC	3360	0.0929	0.2902	0	0	1
lnpop	3360	5.9148	0.6638	3.4002	5.9466	8.1362
lnaca	3351	7.6928	1.3123	2.4849	7.6104	11.2343
lngdp	3360	16.6105	0.9256	14.1773	16.5039	19.8843
Infra	3360	17.6985	7.463	1.37	16.27	60.07
lngov	3360	14.8929	0.7595	12.9718	14.8323	18.2500
lninter	3360	13.4386	0.9627	9.2103	13.4000	17.7617
Urban	3325	0.5522	0.1495	0.1806	0.5347	1
lncoms	3360	15.6009	1.0489	5.4723	15.5572	19.0129

4 EMPIRICAL RESULTS AND ANALYSIS

4.1 Baseline Regression

Table 4's baseline regression confirms H1, showing CBEC pilot areas significantly boost urban innovation (0.1% significance) across all specifications: (1) without controls, (2) with controls, and (3) excluding municipalities. The robust results validate the policy's positive impact.

Table 4 Baseline Regression Results

	Inno (1)	Inno (2)	Inno (3)
CBEC	0.0194***	0.0157***	0.0152***
	(29.77)	(7.81)	(7.25)
Control variable	No	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
N	3360	3316	3269
R-squared	0.5717	0.6432	0.6350

Note: ***, **,and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.2 Parallel Trends Test

The parallel trends assumption was verified through event study analysis (Figure 1), showing consistent pre-policy innovation trends between treatment and control groups (non-significant coefficients). Post-implementation, CBEC pilot cities exhibited significant innovation growth, confirming the policy's effectiveness.

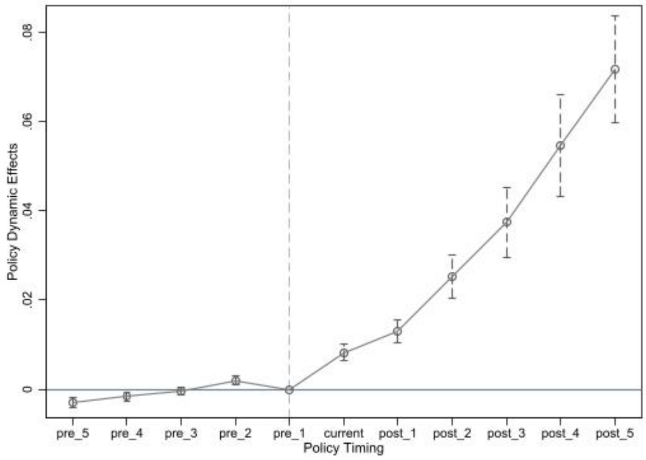


Figure 1 Parallel Trend Test

4.3 Robustness Tests

4.3.1 Placebo test

We conducted a placebo test by constructing random pseudo-treatment groups. As illustrated in Figure 2, which demonstrates that most pseudo-treatment coefficients cluster tightly around zero, with p-values exceeding 0.05, indicating statistical insignificance. This validates the authenticity of CBEC pilot area policy effects.

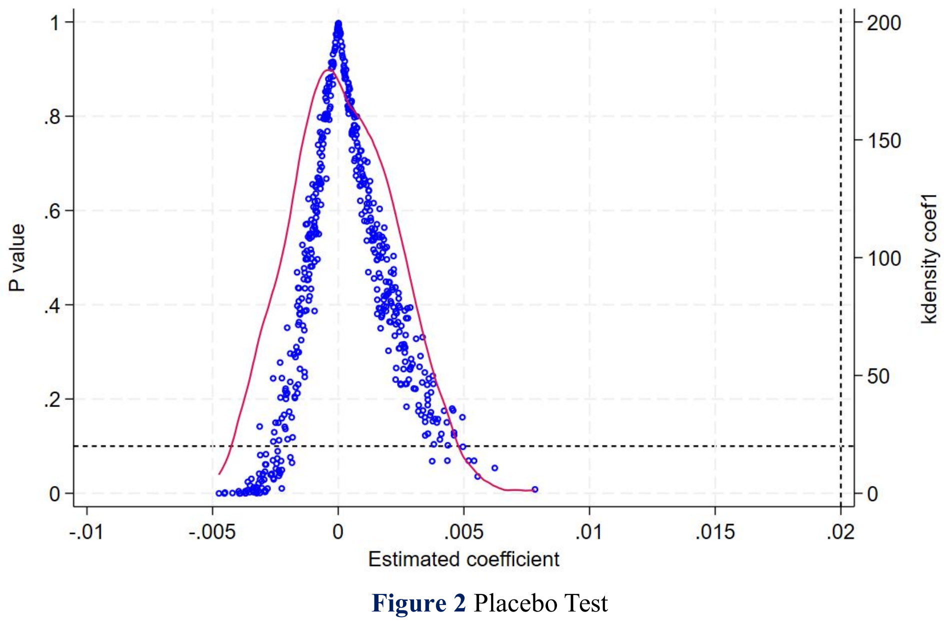


Figure 2 Placebo Test

4.3.2 PSM-DID test

We employ a Probit model to estimate the probability of CBEC pilot area city selection, deriving the propensity score:

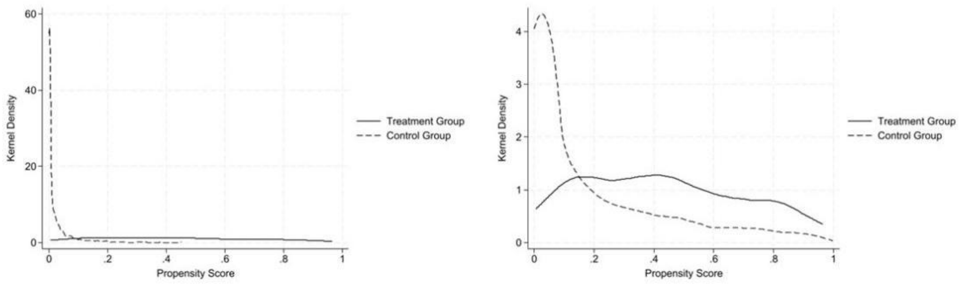
$$probit(treat_i=1)=\alpha+\beta X_i+\varepsilon_i \quad (8)$$

where *treat* is a dummy variable for CBEC pilot area establishment (1 for pilot cities, 0 otherwise), and X represents matching variables including urban innovation index, population, GDP, infrastructure, and other city characteristics. Based on propensity scores, we employ Epanechnikov kernel matching and 5:1 nearest neighbor matching for robustness.

Balance tests demonstrate successful matching with substantially reduced standardized differences between treatment and control groups (Table 5). Common support tests reveal consistent propensity score distributions post-matching with expanded overlap regions (Figure 3), ensuring reliable estimation results.

Table 5 Balance Test Results

Variable	Sample	Mean Difference Test			Standardized Difference	
		Treatment Group	Control Group	t-test (p-value)	Standardized Bias	Reduction (%)
Population (logged)	Unmatched	6.3397	5.8842	11.94(0.000)	72.1	75.8
	Matched	6.3397	6.2293	2.00(0.046)	17.5	
Number of Full-time Teachers in Regular Higher Education Institutions(logged)	Unmatched	9.2327	7.5465	23.08(0.000)	140.0	83.2
	Matched	9.2327	8.9487	2.62(0.009)	23.6	
Regional GDP (logged)	Unmatched	17.909	16.486	28.58(0.000)	167.0	81.5
	Matched	17.909	17.645	3.36(0.001)	31.0	
Per Capita Road Area	Unmatched	18.918	17.498	3.19(0.001)	19.9	41.0
	Matched	18.918	18.08	1.33(0.185)	11.7	
Government General Fiscal Expenditure (logged)	Unmatched	16.005	14.786	30.25(0.000)	166.4	82.0
	Matched	16.005	15.786	3.02(0.003)	29.9	
Urbanization Rate (%)	Unmatched	0.7224	0.5351	22.30(0.000)	141.9	88.4
	Matched	0.7224	0.7006	1.83(0.068)	16.4	
Total Retail Sales of Consumer Goods(logged)	Unmatched	17.005	15.473	27.08(0.000)	166.7	81.5
	Matched	17.005	16.722	3.50(0.001)	30.9	
Internet User Data(logged)	Unmatched	14.785	13.307	28.53(0.000)	190.8	82.5
	Matched	14.785	14.527	3.84(0.000)	33.3	



(a) Before Matching (b) After Matching

Figure 3 Results of the Co-Support Test

We estimated the average treatment effect using kernel matching and 5:1 nearest neighbor matching methods. As shown in Table 6, kernel matching estimates an average treatment effect of 0.0102, while 5:1 nearest neighbor matching estimates 0.0069. These results indicate that CBEC pilot area establishment increased treatment group cities' innovation indices by 0.69%-1.02%, demonstrating the positive role of digital trade policy in strengthening urban innovation capacity.

Table 6 Average Treatment Effects of Digital Trade Policy

	Kernel Matching (1)	5:1 Nearest Neighbor Matching (2)
	Urban Innovation Capacity Index (Inno)	
Average Treatment Effect	0.0102^{***}	0.0069^{*}
	(0.0025)	(0.0030)
Treatment Group Sample	3011	3011
Control Group Sample	305	305
Total Sample	3360	3360

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.4 Heterogeneity Analysis

4.4.1 Geographic location heterogeneity

Table 7 reveals strong regional variation in CBEC policy impacts, with eastern China showing the most significant innovation boost, followed by central and northeastern regions. Western regions show no significant effects, constrained by geographic and industrial limitations.

Table 7 Geographic Location Heterogeneity Test Results

	Eastern region (1)	Central region (2)	Western region (3)	Northeast region (4)
*East * CBEC*	0.0172^{***} (4.73)			
*Mid * CBEC*		0.0100^{*} (2.07)		
*West * CBEC*			0.0067 (1.58)	
*Northeast * CBEC*				0.0080^{*} (2.45)
Control variable	Yes	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
N	3316	3316	3316	3316
R-squared	0.6137	0.5487	0.5430	0.3925

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.4.2 Industrial structure heterogeneity

Table 8 shows CBEC policies significantly boost innovation in service-oriented cities, benefiting from streamlined trade processes and lower costs. However, manufacturing cities show no significant gains, suggesting they may need additional support or industrial upgrading to realize policy benefits.

Table 8 Industrial Structure Heterogeneity Test Results

	Second (1)	Third (2)
*Second * CBEC*	0.00162 (0.67)	
*Third * CBEC*		0.0172^{***} (6.73)
Control variable	Yes	Yes
Urban fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
N	3314	3314
R-squared	0.5382	0.6499

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.4.3 City scale heterogeneity

Table 9 reveals stark contrasts in CBEC policy effects by city size. Megacities show significant innovation gains, leveraging their strong research ecosystems to amplify policy benefits. Conversely, large/medium cities experience negative impacts, as their limited innovation resources make them vulnerable to megacities' resource-siphoning effects under the policy framework.

Table 9 Results of City Size Heterogeneity Test

	mega city (1)	large or medium-sized city (2)
*Large * CBEC*	0.0249^{***} (8.53)	
*Medium * CBEC*		-0.00438^{**} (-3.00)
Control variable	Yes	Yes
Urban fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
N	3316	3316
R-squared	0.7277	0.5417

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.4.4 Urban agglomeration heterogeneity

Table 10 shows significant regional variations in digital trade policy effects. The Yangtze River Delta demonstrates strong positive impacts, benefiting from robust innovation foundations and efficient resource flows. In contrast, Beijing-Tianjin-Hebei's effects are weakened by regional disparities, while the Pearl River Delta shows limited policy dependence despite its innovation strength.

Table 10 Results of City Size Heterogeneity Test

	JJJ (1)	YRD (2)	PRD (3)
*JJJ * CBEC*	0.0087 (1.04)		
*Yangtz * CBEC*		0.0338*** (5.62)	
*Pearl*CBEC*			0.0150 (1.64)
Control variable	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
N	3316	3316	3316
R-squared	0.5401	0.6645	0.5496

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

Through this multidimensional heterogeneity analysis, our study comprehensively reveals the diverse impacts of digital trade policy, specifically the establishment of CBEC pilot areas, on innovation levels across different types of cities, providing more nuanced empirical evidence for policy formulation.

5 MECHANISM TESTING

This section empirically examines through mediation effect analysis whether the three major themes identified in policy texts constitute effective channels through which CBEC pilot areas enhance urban innovation capacity. Recent studies support these mechanisms: digital infrastructure promotes information flow and resource allocation efficiency [13]; service industry agglomeration enhances innovation factor concentration through specialized division of labor [14]; business environment optimization reduces institutional transaction costs and elevates innovation incentives [15-16]. We construct a mediation effect model using the Sobel test:

$$M_{it}=\beta_0+\beta_3 cbec_{it}+\gamma X_{it}+\lambda_i+\mu_i+\varepsilon_{it} \quad (9)$$

$$\gamma_{it}=\beta_0+\beta_1 cbec_{it}+\beta_4 M_{it}+\gamma X_{it}+\lambda_i+\mu_i+\varepsilon_{it} \quad (10)$$

In Equations (9) and (10), M_{it} represents mediating variables, which are substituted with the digital infrastructure index (Diginf), service industry agglomeration index (Spec), and China urban business credit environment index (Envir), while all other variables remain consistent with previous specifications.

5.1 Digital Infrastructure Development

Digital infrastructure serves as the technological foundation for CBEC pilot areas' innovation effects [17-18]. Table 11 reveals these zones significantly boost digital infrastructure, with Sobel tests (16.39) confirming strong mediation. By integrating cross-department digital services, CBEC areas establish comprehensive support systems spanning customs to foreign exchange, reducing information costs and enhancing resource allocation efficiency through digital transformation.

Table 11 Mechanism Test: Digital Infrastructure Construction

	(1)
Variable	Inno
Diginf	0.2024*** (24.29)
CBEC	0.0281*** (28.27)
Sobel Z	16.39***
Control variable	Yes
Urban fixed effect	Yes
Year fixed effect	Yes
N	3336
R-squared	0.5930

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.2 Service Industry Agglomeration

Service industry agglomeration represents the central mechanism through which CBEC pilot areas drive innovation. Research indicates that specialized agglomeration generates significant Marshallian externalities, enhancing regional competitiveness through resource sharing, knowledge spillovers, and specialized labor markets [19-20]. We construct producer service agglomeration indicators using employment proportions:

$$spec_{it}=\frac{\sum_{j=1}^{J} S_{ijt}/\sum_{i=1}^{N}\sum_{j=1}^{J} S_{ijt}}{S_{it}/\sum_{i=1}^{N} S_{it}} \tag{11}$$

Where S_{ijt} represents the total employment in industry j of city i in year t, S_{it} denotes the total employment across all industries in city i in year t, and N represents the number of cities.

Table 12 demonstrates that CBEC pilot areas significantly enhance producer service agglomeration, with the agglomeration index showing a 0.0241 coefficient on innovation capacity. The significant Sobel test confirms strong mediation effects. By fostering industrial ecosystems, these zones facilitate enterprise clustering and knowledge spillovers, accelerating technological diffusion.

Table 12 Mechanism Test: Service Industry Agglomeration

	(2)
Variable	Inno
Spec	0.0241*** (29.44)
CBEC	0.0373*** (30.27)
Sobel Z	12.59***
Control variable	Yes
Urban fixed effect	Yes
Year fixed effect	Yes
N	2799
R-squared	0.6610

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.3 Business Environment Optimization

The business environment serves as a crucial institutional foundation for innovation in CBEC pilot areas. Following Qian and Jia [21-22], we measure it using the China Urban Business Credit Environment Index (Envir). Results (Table 13) show CBEC pilot areas significantly improve business environments (1% significance), with Sobel tests confirming their mediating role in urban innovation. By reducing institutional transaction costs, these zones enhance market credibility, lower innovation uncertainties, and boost R&D investment. Though policy texts allocate only 2.57% to business environment themes, its substantial impact highlights institutional frameworks' fundamental importance in driving innovation.

Table 13 Mechanism Test: Business Environment Optimization

	(3)
Variable	Inno
Envir	0.1597*** (30.38)
CBEC	0.0273*** (28.96)
Sobel Z	16.89***
Control variable	Yes
Urban fixed effect	Yes
Year fixed effect	Yes
N	3350
R-squared	0.6401

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

6 DISCUSSION

This study addresses the fundamental question of how digital trade policies influence urban innovation capacity development in the digital economy era. Based on the interactive relationship between institutional change and technological innovation [12], we investigate whether Cross-border E-commerce (CBEC) Comprehensive Pilot Areas serve as effective policy instruments for enhancing urban innovation, and through what specific mechanisms these effects operate.

CBEC pilot areas significantly enhance urban innovation, with treatment effects of 0.69% to 1.52%. Effects show strong heterogeneity, benefiting Eastern regions, tertiary industry cities, and megacities most. Three mechanisms drive this: digital infrastructure (reducing information costs), service industry agglomeration (knowledge spillovers), and business environment optimization (lowering institutional costs).

These findings align with Schumpeterian theory and industrial cluster theory but reveal greater regional heterogeneity than prior studies Chen and Luo and Li et al. [3, 23-25], highlighting varied absorption capacities across innovation systems [26].

This study advances understanding of digital trade policies by identifying three key transmission mechanisms: digital infrastructure development (3.55% of policy themes), which enhances knowledge application efficiency; service industry agglomeration (4.85%), generating knowledge spillovers; and business environment optimization (2.57%), providing institutional safeguards. However, the analysis is limited by its exclusive focus on China, potentially restricting generalizability, while the interactive relationships between mechanisms and long-term effects beyond 2010-2021 remain underexplored. The findings demonstrate that digital trade policies significantly boost urban innovation, with regional heterogeneity, by optimizing resource allocation and reducing transaction costs. Methodologically, the study integrates qualitative and quantitative approaches for robust policy evaluation. Practically, policymakers should tailor strategies to regional contexts, strengthen synergies among digital infrastructure, service agglomeration, and institutional reforms, and implement dynamic evaluation systems. China's CBEC experience highlights the potential of digital trade policies as innovation catalysts, though local absorption capacities must be considered. Future research should investigate mechanism interactions, heterogeneous effects, and long-term impacts to further refine policy frameworks.

Based on our findings, China's CBEC experience provides three policy implications for other countries:

(1) Tailor digital trade policies. Policy formulation should adapt support measures to urban industrial structures, scale, and development stages, emphasizing enhancement of absorption capabilities in central-western regions and manufacturing-dominated cities to prevent excessive resource concentration.

(2) Strengthen synergistic mechanisms. Digital infrastructure development, service industry agglomeration, and business environment optimization constitute an organic whole for promoting urban innovation. Policy design should comprehensively address these three dimensions to generate concerted effects for innovation factor agglomeration.

(3) Establish dynamic evaluation systems. Develop comprehensive assessment frameworks encompassing innovation outputs, industrial agglomeration, and institutional reforms to promptly identify implementation issues and continuously optimize policy instrument portfolios.

COMPETING INTERESTS

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