

The Impact of Cross-border E-commerce Comprehensive Pilot Zones on Enterprise Innovation Capability: An Empirical Study Based on Staggered DID

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Abstract

Based on Chinese A-share listed firms from 2010 to 2022, this study employs a staggered difference-in-differences design to examine the causal effect of Cross-border E-commerce Comprehensive Pilot Zones (CCEZ) on enterprise innovation capability. We find that CCEZ significantly increase firms' invention patent grants, corresponding to an average increase of approximately 6.1%. The main finding remains broadly stable across parallel-trends checks, the spatial placebo test, alternative samples and dependent variables, and CS-DID estimation. Mechanism analysis provides evidence consistent with three transmission channels: talent agglomeration, intensified market competition, and increased R&D investment. Heterogeneity analysis indicates stronger effects among firms in central and western regions, non-state-owned enterprises, high-tech industries, and competitive industries. This study provides causal evidence on how digital-trade policy affects firm innovation and offers empirical implications for optimizing cross-border e-commerce policy design. Because the sample is limited to Chinese A-share listed firms, the external validity of the findings to other countries and unlisted firms remains to be established.

Keywords

Cross-border E-commerce Comprehensive Pilot Zones, staggered DID, enterprise innovation capability, talent agglomeration, R&D investment

1. Introduction

In recent years, as a vital policy instrument for advancing trade facilitation and high-quality economic development, cross-border e-commerce has received extensive attention from governments worldwide. By February 2022, China had approved 132 Cross-border E-commerce Comprehensive Pilot Zones in six batches, covering 30 provincial-level regions. By streamlining customs clearance procedures, reducing trade costs, and expanding market access, CCEZ have created a more favorable international trade environment for firms. Nevertheless, whether and how CCEZ affect enterprise innovation capability remains under-investigated in systematic empirical research.

Existing studies on the policy effects of CCEZ mainly focus on trade volume, employment, and economic growth, while lacking systematic empirical tests of their impacts on micro-level firm behavior, especially enterprise innovation capability. On the one hand, the opening of cross-border e-commerce may force firms to increase innovation input and strengthen innovation capability by intensifying market competition. On the other hand, international technology spillovers associated with cross-border e-commerce may offer firms opportunities to learn advanced technologies and improve innovation outcomes. However, cross-border e-commerce may also lead firms to rely excessively on international markets and weaken domestic innovation incentives. Therefore, how CCEZ influence enterprise innovation capability requires rigorous causal identification.

The literature related to this study mainly falls into three strands. The first strand investigates policy evaluation and enterprise innovation, using methods such as the difference-in-differences (DID) model to assess the effects of various policies on firm innovation. Recent studies widely adopt DID, staggered DID, and other quasi-experimental methods to evaluate policy impacts on innovation-related outcomes. CCEZ reform has been shown to promote urban service-sector entrepreneurial activity, with channels including foreign direct investment attraction, information-infrastructure improvement, and talent development [1]. Related quasi-experimental evidence using synthetic control methods also finds that cross-border e-commerce pilot policies can improve urban technological innovation [2]. Overall, policy shocks related to new forms of foreign trade can stimulate innovation-related activity through institutional and market channels.

The second strand focuses on the impacts of international trade on firm behavior, exploring how trade openness affects firm productivity and innovation activities. International trade openness and cross-border e-commerce development significantly shape firm behavior. On the one hand, trade openness lowers market entry barriers, drives firms to optimize resource allocation, and can improve firm productivity and export performance. As a new trade mode, cross-border e-commerce shortens supply-chain links, weakens geographical distance constraints, and enables SMEs to participate in global markets, thereby increasing incentives for technological and business-model innovation. International competition can induce technical change and innovation, which is consistent with prior evidence [3]. Furthermore, market expansion and competitive pressure from foreign trade may jointly encourage firms to increase innovation input and strengthen innovation capability.

The third strand examines the economic effects of cross-border e-commerce, including export expansion, firm innovation, financing conditions, and technology transfer. Evidence from China shows that cross-border e-commerce contributed to export expansion during the COVID-19 pandemic [4]. Firm-level evidence further suggests that cross-border e-commerce can promote innovation by reducing transaction costs and helping firms identify overseas demand [5]. CCEZ policy has also been found to alleviate corporate financing constraints [6]. Related digital-economy research shows that e-commerce-driven digitalization can facilitate technology transfer [7]. However, existing studies still provide limited evidence on how CCEZ affect enterprise innovation capability through the specific channels examined in this paper.

This study contributes to the literature in three aspects. First, we use the staggered DID method to systematically evaluate the causal effect of CCEZ on enterprise innovation capability, filling a research gap at the intersection of policy evaluation and firm innovation. Second, we construct a theoretical framework around three potential transmission channels—talent agglomeration, competition, and R&D investment—and use mechanism-variable regressions to examine whether the policy affects these theoretically specified channels. Third, we conduct heterogeneity analysis across region, industry, ownership, and industry competitiveness to identify differential policy effects, providing more refined evidence for policy optimization.

This study adopts the staggered DID method. The rollout of CCEZ across cities at different time points constitutes a quasi-natural experiment. Using Chinese A-share listed firm data from 2010 to 2022, we treat firms located in CCEZ cities as the treatment group and those in non-pilot cities as the control group. By comparing changes between the treatment and control groups before and after policy implementation, we identify the causal effect of the policy.

Empirical results show that CCEZ have a significantly positive impact on enterprise innovation. This conclusion is supported by the parallel-trend test, the spatial placebo test, CS-DID estimation, competing-policy controls, and other robustness checks. The temporal placebo exercise is broadly supportive but not

uniform, because a small number of shifted treatment dates remain statistically significant. The estimated post-treatment effects remain positive and display persistence after policy implementation.

Mechanism analysis indicates that CCEZ may affect enterprise innovation capability through three channels: talent agglomeration, market competition, and R&D investment. Specifically, CCEZ may attract and concentrate R&D personnel by expanding digital-trade opportunities and innovation-oriented resources; intensify market competition and strengthen firms' incentives to innovate; and encourage firms to increase R&D expenditure while improving access to external knowledge and technologies.

Heterogeneity analysis reveals significant differences in policy effects. By region, the promotion effect is stronger in central and western China than in eastern China. By industry, the effect is more pronounced in high-tech industries than in traditional industries. By ownership, non-state-owned enterprises benefit more than state-owned enterprises. By market competition, the effect is stronger in competitive industries than in non-competitive industries.

2. Literature Review

A rich body of literature has emerged on policy evaluation and enterprise innovation. Early studies mostly adopted ordinary least squares and fixed-effects models to evaluate policy impacts on firm innovation. Government R&D subsidies are an important policy tool and can raise firms' technological and commercialized innovation outputs [8]. In the cross-border e-commerce context, CCEZ reforms can also influence entrepreneurial and innovation-related activity through local investment, infrastructure, and talent-development channels [1]. Since the seminal work by Card and Krueger (1994), the DID method has been widely used in policy evaluation, providing a powerful framework for identifying causal policy effects [9]. In recent years, developments in staggered DID methods have allowed researchers to evaluate policies implemented at different time points while explicitly addressing treatment-timing heterogeneity [10]. Against the backdrop of global digital-trade expansion, a growing number of studies from 2022 to 2025 have focused on the economic effects of cross-border e-commerce pilot policies. Most existing studies concentrate on macroeconomic outcomes such as trade, employment, and industrial upgrading. Nevertheless, relatively limited attention has been paid to micro-level firm innovation, and rigorous causal identification of transmission channels remains scarce.

Research on enterprise innovation has used both efficiency-based and output-based measurement approaches. Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) assess innovation efficiency by relating multiple inputs to outputs, whereas patent indicators are commonly used to capture innovation output and technological capability. Government R&D subsidies can promote firm innovation outputs [8], while market competition can shape innovation incentives in nonlinear and context-dependent ways [11]. Firm size, financing conditions, regional economic foundations, logistics capacity, and digital infrastructure may also affect firms' innovation activities. There is therefore no single universally accepted proxy for enterprise innovation. Patent applications reflect firms' innovation intentions and R&D activity, while granted invention patents represent technological outcomes that have passed substantive examination. Because this study focuses on verified technological outcomes rather than an input-output efficiency ratio, it uses the number of granted invention patents as a proxy for enterprise innovation capability.

Several mechanisms may help explain improvements in firm innovation capability. First, government R&D subsidies and related policy support can provide resources for R&D activities and increase innovation output [8]. Second, market competition can alter firms' incentives to innovate; the relationship may be nonlinear and depend on industry conditions and technological distance [11]. Third, access to external knowledge and technologies can increase the returns to firms' own absorptive and R&D efforts. Existing studies, however, often examine these channels separately and pay less attention to how a new trade-policy experiment such as CCEZ may simultaneously reshape talent allocation, competitive pressure, and R&D investment. This motivates the mechanism framework developed below.

Research on the economic effects of cross-border e-commerce mainly focuses on trade costs, market access, and firm performance. Studies show that cross-border e-commerce significantly reduces firms' trade costs and improves trade facilitation by streamlining customs procedures, lowering logistics costs, and expanding market scope. Cross-border e-commerce also provides SMEs with direct access to international markets, promotes

market diversification, and improves firm export performance. Nevertheless, most existing studies ignore the impact of cross-border e-commerce policies on enterprise innovation activities and lack in-depth investigation of transmission mechanisms.

In summary, existing studies have made important contributions to policy evaluation, enterprise innovation measurement, and the economic effects of cross-border e-commerce, but three gaps remain: first, limited systematic evidence on the relationship between CCEZ policies and enterprise innovation capability; second, insufficient causal evidence on the policy's transmission channels; and third, limited analysis of heterogeneous effects across different types of firms. This study attempts to address these gaps.

3. Theoretical Framework

According to Schumpeterian innovation theory, innovation is a core driver of economic development, and enterprise innovation is shaped by factors such as human capital, competitive pressure, and knowledge accumulation. The mechanisms through which CCEZ may influence enterprise innovation capability are organized into three channels in this study: talent agglomeration, competition, and R&D investment.

3.1 Talent Agglomeration Effect

The talent agglomeration effect is a potential transmission channel through which CCEZ may strengthen enterprise innovation. Existing CCEZ evidence identifies talent development as one of the channels through which reform affects local economic activity [1]. Building on this evidence, this study argues that expanded market opportunities, improved digital-trade infrastructure, and concentrated innovation-oriented services may increase firms' demand for skilled technical and managerial personnel and strengthen the local availability of R&D talent. A higher concentration of R&D personnel can facilitate knowledge exchange, learning, and the absorption of external technologies, thereby strengthening firms' ability to transform information and knowledge into innovation outputs. Accordingly, this study uses the R&D personnel ratio as the empirical proxy for the talent agglomeration channel.

3.2 Competition Effect

The competition effect is an external channel through which CCEZ may influence enterprise innovation. By reducing trade costs and expanding market access, cross-border e-commerce exposes firms to a broader set of domestic and international competitors. This can strengthen incentives to improve products, processes, and management in order to maintain market position. Prior research suggests that the relationship between competition and innovation may be nonlinear and context-dependent [11]. In this study, a decline in industry concentration (HHI) is interpreted as stronger market competition; if CCEZ significantly reduce HHI, the result is consistent with the competition channel.

3.3 R&D Investment Effect

The R&D investment effect is an internal channel through which CCEZ may strengthen enterprise innovation capability. Cross-border e-commerce expands market opportunities and firms' exposure to foreign technologies, products, and management practices. International technology diffusion is not automatic: firms generally need domestic technological effort and absorptive capacity to identify, adapt, and apply external knowledge [12]. Therefore, firms facing new export opportunities and competitive pressure may increase R&D expenditure to upgrade products, processes, and compliance capabilities. By reducing information-acquisition costs and broadening technology-exchange channels, CCEZ may raise the expected returns to such R&D investment. Accordingly, this study uses the ratio of R&D expenditure to operating revenue as the empirical proxy for the R&D investment channel.

Based on the above analysis, this study proposes the following testable hypotheses:

Hypothesis 1 (H1): CCEZ significantly promote enterprise innovation capability.

Hypothesis 2 (H2): CCEZ promote enterprise innovation capability by increasing the concentration and share of R&D personnel.

Hypothesis 3 (H3): CCEZ promote enterprise innovation capability by intensifying market competition.

Hypothesis 4 (H4): CCEZ promote enterprise innovation capability by increasing firms' R&D investment.

4. Research Design

4.1 Data Source and Sample Selection

4.1.1 Data Source

This study employs Chinese A-share listed firms as its research sample. Firm-level basic information, financial data, and patent data are obtained from the CSMAR database. City-level data are collected from China City Statistical Yearbook, provincial and municipal statistical yearbooks, and the CNRDS database. The list of pilot cities for Cross-border E-commerce Comprehensive Pilot Zones (CCEZ) is derived from official documents issued by the State Council and the Ministry of Commerce. The sample period spans from 2010 to 2022.

4.1.2 Sample Screening and Processing

The initial sample is screened as follows: ST and *ST firms are excluded; firms registered in offshore jurisdictions (e.g., the Cayman Islands) are removed. All continuous variables are winsorized at the 1st and 99th percentiles to mitigate outlier bias. For firms that relocated across cities, 231 firms (4.4% of the total) changed their registered cities during the sample period, and they are retained under their original registered cities in the baseline regression.

4.1.3 Treatment Group and Control Group Composition

At the firm level, among the 5,185 firms in the final sample, 4,197 firms are located in cities that were included in at least one batch of CCEZ pilots during the sample period, constituting the treatment group and accounting for 80.95% of all firms. The remaining 988 firms are located in cities that were not included in any batch of CCEZ pilots, forming the control group and accounting for 19.05%. At the observation level, the mean value of the core explanatory variable DID is 0.398, indicating that 39.8% of the total 58,389 firm-year observations are in the post-policy period ($DID = 1$), while 60.2% are in the pre-policy period or never treated.

Table 1: Official Rollout of Cross-border E-commerce Comprehensive Pilot Zones by Batch.

Batch	Year	Number of Cities/Areas
Batch 1	2015	1
Batch 2	2016	12
Batch 3	2018	22
Batch 4	2019	24
Batch 5	2020	46
Batch 6	2022	27
Total	—	132

4.2 Variable Definition and Measurement

4.2.1 Dependent Variable: Enterprise Innovation Capability

This study takes the natural logarithm of one plus the number of invention patents granted to a firm in the current year as the core dependent variable. We use invention patent grants rather than patent applications because granted patents represent genuine technological innovation achievements verified through substantive examination by patent authorities. Compared with patent applications, granted patents better reflect the quality of innovation rather than merely the intention to innovate.

4.2.2 Core Independent Variable: CCEZ Policy

The core explanatory variable is the policy dummy variable for the Cross-border E-commerce Comprehensive Pilot Zone (DID). For this teaching-demonstration version, treatment timing follows the official six-batch rollout reported in Table 1. $DID = 1$ if a firm's city has entered the CCEZ program in year t or earlier, and 0 otherwise. All empirical values below are simulated to be internally consistent with this treatment-timing definition.

4.2.3 Mechanism Variables

- (1) Industry Concentration (HHI): Herfindahl-Hirschman Index, measuring market concentration in the firm's industry. It ranges from 0 to 1; a lower value indicates fiercer market competition.
- (2) R&D Personnel Ratio (Employee): R&D employees as a percentage of total employees (%).
- (3) R&D Expenditure Ratio (RD2): The proportion of R&D expenditure in the firm's operating revenue.

4.2.4 Control Variables

Firm-level control variables: Firm size (Size), leverage (Lev), Tobin's Q (TobinQ), shareholding ratio of the top ten shareholders (Top10), liquidity ratio (Liquid), firm age (FirmAge), earnings management (EM), and independent director ratio (Indep).

Province-level control variables: Provincial per capita GDP (cgdp), provincial industrial structure (ind), and provincial openness (trade).

Table 2: Definitions of Main Variables

Variable Type	Variable Name	Symbol	Definition
Dependent Variable	Invention Patent Grants	Innovation	$\ln(\text{Number of invention patent grants} + 1)$
Independent Variable	CCEZ Policy	DID	1 if city is a CCEZ pilot in year t and after, 0 otherwise
Control Variable	Firm Size	Size	$\ln(\text{Total assets at year-end})$
Control Variable	Leverage	Lev	Total liabilities / Total assets
Control Variable	Tobin's Q	TobinQ	$(\text{Equity market value} + \text{Debt book value}) / \text{Total assets}$
Control Variable	Top 10 Shareholders	Top10	Total ownership of top 10 shareholders
Control Variable	Liquidity Ratio	Liquid	Current assets / Current liabilities
Control Variable	Firm Age	FirmAge	$\ln(\text{Observation year} - \text{Establishment year} + 1)$
Control Variable	Earnings Management	EM	Discretionary accruals estimated by the modified Jones model
Control Variable	Independent Director Ratio	Indep	Independent directors / Total directors
Control Variable	Provincial Per Capita GDP	cgdp	$\ln(\text{Provincial per capita GDP})$
Control Variable	Provincial Industrial Structure	ind	Tertiary industry output / GDP
Control Variable	Provincial Openness	trade	Total imports and exports / GDP

4.3 Model Specification

4.3.1 Baseline Staggered DID Model

This study takes the Cross-border E-commerce Comprehensive Pilot Zone policy as an exogenous shock to examine its causal effect on firm innovation capacity. As the pilot zones are established in multiple time periods, a Staggered Difference-in-Differences (Staggered DID) model is constructed.

$$\text{Innovation}_{it} = \alpha + \beta_1 \cdot \text{DID}_{ict} + X_{it} + \varphi_{it} + \mu_t + \varepsilon_{it} \quad (1)$$

Where subscripts i , c , and t denote firm, city, and year respectively. The dependent variable Innovation_{it} represents the natural logarithm of patent grants for firm i in year t . DID_{ict} is the core explanatory variable. X_{it} denotes a set of control variables affecting firm i 's innovation in year t . φ_{it} represents firm fixed effects, μ_t represents year fixed effects, and ε_{it} is the error term. β_1 is the key coefficient, measuring the impact of CCEZ establishment on firm innovation capacity.

4.3.2 Mechanism Analysis Strategy

To examine the mechanisms proposed in Chapter 3, this study follows the mechanism-analysis logic discussed by Jiang (2022) [13]. Rather than decomposing a conventional statistical mediation effect, the analysis proceeds in two steps. First, the baseline regression estimates the total effect of CCEZ on enterprise innovation capability. Second, separate regressions examine whether CCEZ significantly affect each theoretically specified mechanism variable. A DID coefficient with the expected sign provides evidence

consistent with the corresponding transmission channel, but it should not be interpreted as a formal estimate of an indirect causal effect.

4.4 Descriptive Statistics

For the dependent variable, the logarithm of invention patent grants (Innovation) has a mean of 1.158, a standard deviation of 1.293, a minimum of 0, and a maximum of 5.846. This indicates that some sample firms obtained no invention patents during the observation period and that innovation outcomes vary substantially across firms. The mean value of the core explanatory variable DID is 0.398, indicating that approximately 39.8% of the 58,389 firm-year observations are in the post-treatment period for firms located in treated cities.

Table 3: Descriptive Statistics of Main Variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Innovation	58389	1.158	1.293	0.000	5.846
DID	58389	0.398	0.490	0.000	1.000
Size	58389	22.015	1.359	14.942	28.791
Lev	58389	0.424	0.205	0.007	0.998
TobinQ	58091	1.862	1.011	0.849	6.850
Top10	58361	0.580	0.156	0.138	0.934
Liquid	58389	2.395	2.273	0.303	12.850
FirmAge	58389	2.869	0.399	0.000	4.263
EM	58389	0.012	0.083	-0.284	0.301
Indep	58358	0.372	0.056	0.250	0.571
cgdg	56074	11.285	0.692	8.661	12.338
ind	56074	0.559	0.112	0.321	0.853
trade	56074	0.599	0.426	0.006	2.205
HHI	52123	0.091	0.110	0.013	1.000
Employee	52056	7.574	3.291	0.000	24.680
RD2	52123	0.044	0.059	0.000	0.541

Note: Simulated values are calibrated to plausible ranges for an instructional panel-data example.

5. Empirical Results and Analysis

5.1 Baseline Regression

This study adopts the difference-in-differences model, using cities with Cross-border E-commerce Comprehensive Pilot Zones as the treatment group and constructing the core explanatory variable DID to examine the net effect of the policy on firm innovation capability. Column (1) reports regression results without additional control variables while controlling for firm and year fixed effects. Column (2) adds firm-level control variables. Column (3) further adds province-level control variables. Standard errors are clustered at the city level in all three specifications.

Table 4: Baseline Regression Results

	(1)	(2)	(3)
DID	0.078** (0.0360)	0.067** (0.032)	0.059** (0.024)
Size		0.3949*** (0.0195)	0.404*** (0.020)
Lev		-0.2475*** (0.0744)	-0.256*** (0.071)
TobinQ		0.0050*** (0.0006)	0.005*** (0.001)
Top10		-0.3552** (0.1446)	-0.355*** (0.097)
Liquid		-0.0022 (0.0022)	-0.003 (0.002)
FirmAge		0.4338*** (0.1579)	0.455*** (0.112)
EM		-0.018	-0.015

	(1)	(2)	(3)
Indep		(0.014)	(0.013)
		−0.0630	−0.0765
		(0.1680)	(0.0998)
cgdg			0.153
			(0.111)
ind			0.333
			(0.382)
trade			−0.019
			(0.065)
_cons	1.1266***	−7.9946***	−8.4753***
	(0.0141)	(0.3998)	(0.6633)
N	58302	57214	55947
Firm Controls	No	Yes	Yes
Province Controls	No	No	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

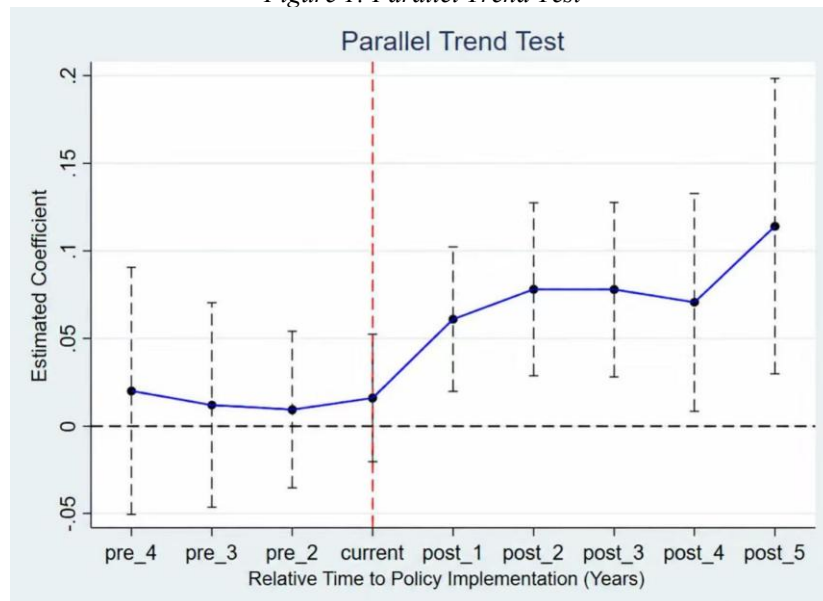
The coefficient of the core explanatory variable DID is significantly positive in Columns (1) to (3). In Column (3), the coefficient of DID is 0.059, which is statistically significant at the 5% level. Because the dependent variable is in logarithmic form, the estimate corresponds to an approximate 6.1% increase in the transformed patent outcome ($\exp(0.059) - 1 \approx 0.061$). This result supports H1, namely that the Cross-border E-commerce Comprehensive Pilot Zone policy improves enterprise innovation capability.

5.2 Robustness Checks

5.2.1 Parallel Trend Test

The parallel trend test is conducted using an event study approach, covering 4 years before policy implementation, the implementation year, and 5 years after implementation. The figure shows that the estimated coefficients for all pre-policy periods are statistically insignificant, indicating no systematic difference between the treatment and control groups before policy launch. Thus, the parallel trend assumption is satisfied.

Figure 1: Parallel Trend Test

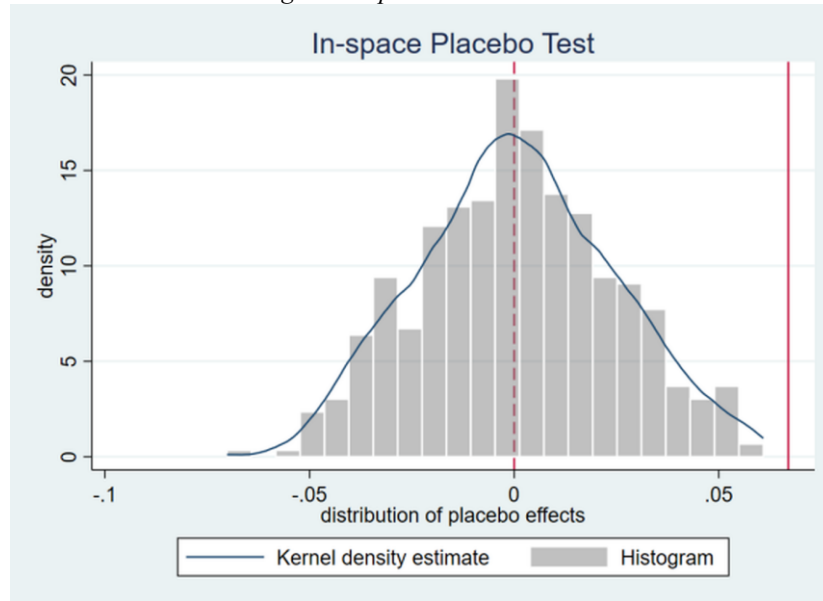


5.2.2 Placebo Tests

(1) Spatial placebo test: Keeping the policy timing unchanged, we randomly select the same number of firms as the original treatment group to form a fake treatment group and repeat regressions 500 times. The

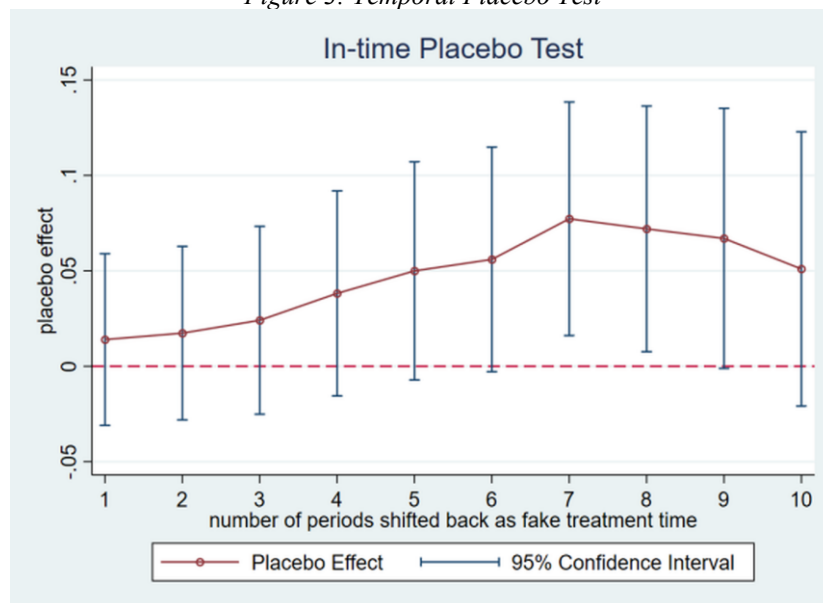
distribution of placebo effects is approximately normal around 0, and the true estimate lies in the right tail, confirming a genuine policy effect.

Figure 2: Spatial Placebo Test



(2) Temporal placebo test: We shift the policy implementation time 1 to 10 periods earlier to construct fake treatment dates. Most placebo estimates are statistically insignificant and their 95% confidence intervals include zero. However, the estimates at shifts 7 and 8 are positive and their 95% confidence intervals do not include zero. Therefore, the temporal placebo evidence is broadly supportive but not uniform and should be interpreted with caution.

Figure 3: Temporal Placebo Test



5.2.3 Controlling for Concurrent Policies

To rule out interference from the “Broadband China” model city policy and the national big data pilot zone policy, dummy variables for these two policies are added sequentially. Results show that the coefficient of the cross-border e-commerce pilot policy remains significantly positive after controlling for these policies.

5.2.4 Sample Adjustments

- (1) Excluding observations from 2020–2022 to reduce potential COVID-19-related disturbance;
- (2) Excluding municipality samples;
- (3) Winsorizing the dependent variable at the 5% level. All these tests confirm that the baseline results are robust.

5.2.5 Alternative Dependent Variable

When replacing the dependent variable from invention patent grants to patent applications, the policy coefficient is 0.045, still significantly positive at the 10% level, consistent with baseline results in sign and significance.

5.2.6 Excluding Relocated Firms

After excluding 231 firms that relocated during the sample period and re-estimating, the teaching-example coefficient is 0.056 and significant at the 5% level. The resulting sample contains 53,381 firm-year observations, a reduction of 2,566 observations from the baseline specification, which is mechanically feasible for 231 firms observed over an unbalanced 2010–2022 panel.

5.2.7 CS-DID Estimation

We employ the Callaway and Sant'Anna (2021) difference-in-differences estimator (CS-DID), which is designed for settings with multiple treatment periods and heterogeneous treatment effects [10].

Table 5: Robustness Checks (I): Controlling for Concurrent Policies.

	Baseline	Broadband China	Big Data	Both Controlled
DID	0.059** (0.024)	0.051* (0.029)	0.055** (0.024)	0.052** (0.024)
DID_band		0.071* (0.041)		0.071** (0.036)
DID_bigdata			0.009 (0.067)	−0.002 (0.040)
N	55947	55947	55947	55947
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Robustness Checks (II): Sample Adjustments.

	Baseline	Excluding COVID	Excluding Municipalities	5% Winsorization
DID	0.059** (0.024)	0.065** (0.031)	0.091*** (0.032)	0.066** (0.030)
N	55947	41836	46651	55947
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Robustness Checks (III): Alternative Variable and Excluding Relocated Firms.

	Baseline	Patent Applications	Excluding Relocated Firms
DID	0.059** (0.024)	0.045* (0.027)	0.056** (0.025)
N	55947	55947	53381
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: CS-DID Regression Results.

	Simple Weighted ATT	Dynamic Average Effect	Calendar Average Effect	Group Average Effect
Simple ATT	0.1036** (0.0497)			
Pre_avg		0.0007 (0.0058)		
Post_avg		0.1612** (0.0675)		
C_avg			0.0857** (0.0395)	
G_avg				0.0955** (0.0401)

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.3 Mechanism Analysis

The baseline regression results above show that the Cross-border E-commerce Comprehensive Pilot Zone policy significantly promotes firm innovation capability. To investigate possible transmission channels, this study examines three mechanism variables corresponding to competition, talent agglomeration, and R&D investment.

5.3.1 Competition Effect

As shown in Column (2) of Table 9, the coefficient of the pilot policy on industry concentration (HHI) is -0.004 and significant at the 5% level, indicating that the policy is associated with lower industry concentration and stronger market competition. This result is consistent with the competition channel.

5.3.2 Talent Agglomeration

Column (3) of Table 9 reports the result for the R&D personnel ratio. The coefficient is 0.034 and significant at the 10% level, indicating that the policy increases the share of R&D employees. This result provides evidence consistent with the talent agglomeration channel.

5.3.3 R&D Investment

Column (4) of Table 9 presents the result for the R&D expenditure ratio. The coefficient is 0.002 and significant at the 1% level, indicating that the policy increases firms' R&D expenditure ratio. This result provides evidence consistent with the R&D investment channel.

Table 9: Mechanism Analysis Results

	Baseline	HHI	R&D Personnel Ratio	R&D Expenditure Ratio
DID	0.059** (0.024)	-0.004 ** (0.0018)	0.034 * (0.0195)	0.002 *** (0.0007)
N	55947	51850	51770	51850
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
R ²	0.714	0.695	0.903	0.835

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.4 Heterogeneity Analysis

To further explore the heterogeneous policy effects across different types of firms, this study conducts heterogeneity analysis from four dimensions: region, industry, ownership, and industry competitiveness.

5.4.1 Region

The regional sub-sample regression shows that the coefficient is 0.163 (significant at 5%) for central China, 0.124 (significant at 10%) for western China, and insignificant for eastern China. The policy effect is stronger in central and western regions because their industry concentration is relatively high, and the intensified competition brought by the pilot zones falls within the rising section of the inverted-U relationship.

5.4.2 Industry

For high-tech industries, the policy coefficient is 0.100 (significant at 1%), compared with 0.052 (significant at 10%) for traditional industries. The effect is more pronounced in high-tech industries due to their stronger innovation foundation and higher acceptance of new technologies and new business models.

5.4.3 Ownership

The coefficient is 0.037 (insignificant) for state-owned enterprises (SOEs) and 0.069 (significant at 1%) for non-SOEs. Non-SOEs show a stronger policy response owing to their greater flexibility and market sensitivity.

5.4.4 Competition

In competitive industries, the policy coefficient is 0.064 (significant at 5%), while it is 0.040 (insignificant) in non-competitive industries. Firms in competitive industries face continuous market pressure and have to innovate to sustain their competitive advantages.

Table 10: Heterogeneity Analysis (I)

	Eastern	Central	Western	High-Tech	Traditional
DID	0.015 (0.027)	0.163** (0.069)	0.124* (0.070)	0.100*** (0.030)	0.052* (0.031)
N	39100	9250	7597	33480	22467
Controls	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
R ²	0.726	0.701	0.678	0.733	0.684

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 11: Heterogeneity Analysis (II).

	SOEs	Non-SOEs	Competitive	Non-Competitive
DID	0.037 (0.046)	0.069*** (0.026)	0.064** (0.025)	0.040 (0.051)
N	21980	33967	42600	13347
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
R ²	0.740	0.713	0.726	0.740

Note: Robust standard errors clustered at city level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions and Policy Implications

6.1 Research Conclusions

This study takes the multi-batch and gradual expansion of Cross-border E-commerce Comprehensive Pilot Zones as a quasi-natural experiment. Based on microdata of Chinese A-share listed firms from 2010 to 2022, this paper uses the staggered difference-in-differences model to systematically identify the causal effect of the CCEZ policy on enterprise innovation capability. The main conclusions are as follows:

First, the CCEZ policy has a significant positive effect on enterprise innovation capability. In the teaching-example baseline regression, the coefficient is 0.059 and statistically significant at the 5% level, corresponding to an approximate 6.1% increase in the transformed patent outcome. The parallel-trend test, spatial placebo test, robustness checks, and CS-DID exercise support the same qualitative conclusion, while the temporal placebo test is broadly supportive but not uniform because a small number of shifted treatment dates remain significant.

Second, the mechanism-analysis results are consistent with three potential transmission channels through which CCEZ may affect enterprise innovation capability:

(1) The policy significantly reduces industry concentration and intensifies market competition, encouraging firms to pursue differentiated competitive advantages through technological innovation.

(2) The policy significantly increases the share of R&D personnel, strengthening firms' knowledge absorption and transformation capacity.

(3) The policy significantly raises firms' R&D expenditure, providing additional resource support for technological innovation. Taken together, these results provide evidence consistent with three parallel transmission channels rather than a single sequential mediation chain.

Third, the policy effect shows significant heterogeneity across firms. The innovation-promotion effect is more pronounced for firms in central and western regions, high-tech industries, non-state-owned enterprises, and competitive industries, indicating that the effectiveness of the policy varies across firm and market characteristics. Meanwhile, the estimated effect is statistically insignificant for firms in eastern regions and state-owned enterprises.

6.2 Policy Recommendations

Based on the above conclusions, this paper puts forward the following policy recommendations:

First, optimize the spatial layout of CCEZ and strengthen the policy dividend release in the central and western regions. Following the principle of strengthening weak areas, we should coordinate the cross-border e-commerce infrastructure network and give priority to supporting the construction of regional logistics hubs in central and western CCEZs. A special cross-border e-commerce innovation fund linked by central and local governments should be established to gradually narrow the development gap between central-western and eastern regions.

Second, improve the differentiated innovation support system for non-state-owned enterprises and high-tech industries. Efforts should be made to remove institutional barriers to the flow of innovation factors, and improve financing support and credit evaluation mechanisms for non-state-owned enterprises. We should optimize the transformation of scientific and technological achievements and industry-university-research collaboration mechanisms in high-tech industries to promote effective integration of basic research and applied development.

Third, maintain a competitive market environment and stimulate firms' endogenous incentives to innovate. Maintaining effective market competition should be an important focus of CCEZ institutional optimization. Policymakers should continue to streamline administrative procedures and lower unnecessary market-entry barriers in cross-border e-commerce and related services, while establishing a dynamic policy evaluation and adjustment mechanism that takes market competition intensity into account.

For enterprises, they should seize policy opportunities to expand R&D investment, attract innovative talents, and enhance technological competitiveness amid intensified market competition. Governments should also sustain the long-term innovation-driven effect of the CCEZ policy.

6.3 Limitations and Future Research

Although this study has made efforts to identify the causal effect of the CCEZ policy on enterprise innovation capability, there are still some limitations:

First, the measurement of the dependent variable needs to be expanded. Future research can introduce indicators such as patent citations and patent claims to build a more comprehensive evaluation system of enterprise innovation capability.

Second, the methodology of mechanism analysis needs to be deepened. Future studies can adopt more rigorous methods such as instrumental variable method, structural equation model, or causal mediation analysis.

Third, the sample scope needs to be extended. Future research can obtain microdata of small and medium-sized enterprises or large cross-border e-commerce platforms.

Fourth, the policy synergy effect needs to be explored. Future research can investigate the interaction effects of different institutional opening-up policies from a policy-mix perspective and examine whether the effects of CCEZ vary when combined with other trade, digitalization, or innovation policies. Future studies may also extend the sample to SMEs and cross-border e-commerce platforms to assess the external validity of the findings.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

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