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Innovation behavior under the belt and road initiative: enhancing innovation capacity in Chinese listed firms

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Abstract

Purpose – This paper aims to examine the multifaceted impact of China's belt and road initiative (BRI) on firm innovation. It investigates how enhanced connectivity, economic cooperation and improved resource access under BRI contribute to the innovation capacity of businesses.

Design/methodology/approach – Taking firms engaged in the BRI framework as the research object, the study uses an empirical analysis to assess the influence of BRI on firm innovation. The analysis focuses on two channels through which BRI operates: optimizing the financing environment and enhancing human capital.

Findings – The empirical results reveal that BRI significantly promotes firm innovation. It suggests that BRI-driven policies effectively alleviate financial constraints and facilitate access to new markets and resources, thereby spurring innovation in technology, products and services.

Originality/value – This study contributes to the literature on international cooperation and firm innovation by providing novel empirical evidence on the role of BRI in advancing firm innovation. The findings offer valuable insights for policymakers seeking to stimulate innovation through global economic initiatives.

Keywords Belt and road initiative, Firm innovation, Human capital, Financing constraints, Industry competition, Information asymmetry

Paper type Research paper

1. Introduction

Since 2013, China has proposed the belt and road initiative (BRI), aiming to foster shared prosperity and development among countries along its route through enhanced connectivity and economic cooperation (Huang, 2016). This initiative not only serves as a platform for infrastructure development and economic cooperation among countries but also has profound implications at the corporate level. It offers valuable lessons and inspiration for other nations.

In the context of globalization and the rapid advancement of information technology, enterprise innovation capacity (Inno) has emerged as the core driving force for corporate survival and development. Whether it involves breakthroughs at the frontiers of science and technology

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or shifts in business models, innovation is not only a crucial means of enhancing enterprise competitiveness but also a vital engine for driving economic growth and social progress (Da *et al.*, 2011). In this context, BRI, as a key international cooperation strategy proposed by China, seeks to establish a more open and mutually beneficial platform for economic cooperation by enhancing infrastructure connectivity, trade and financial integration among the countries along its route, thus offering new opportunities and momentum for Inno (Wang *et al.*, 2023b). Since its inception, BRI has driven the process of economic integration among countries and regions along its route through policy guidance, financial support and international cooperation (Kline *et al.*, 2019). This process has provided enterprises with more resources and markets, thereby fostering innovation in technology, products and services. For instance, BRI enables enterprises to access more information about international markets and understand the technological needs and market trends of various countries and regions, allowing them to conduct more targeted technological research and development and product innovation. In addition, the government has assisted enterprises in overcoming financial challenges during the innovation process by establishing special funds and offering financial support, thereby reducing the burden of innovation. Furthermore, BRI has invigorated innovation by enhancing talent exchange and technological cooperation. Through international talent exchanges, enterprises can absorb and learn from advanced technologies and management practices globally, thereby enhancing their own innovation capabilities (Xuan and Peng, 2022). Concurrently, through technological cooperation and joint research and development, enterprises can collaborate with internationally renowned scientific research institutions and companies on technological research, thereby shortening innovation cycles and enhancing innovation efficiency (Xiang *et al.*, 2022).

In this context, innovation is not only a means for enterprises to enhance their competitiveness but also a critical pathway to realizing the goals of BRI (Brem and Nylund, 2021). Through innovation, enterprises can distinguish themselves in fierce international competition and secure advantageous market positions, thereby promoting economic development in countries and regions along the route and achieving mutual benefit. Therefore, examining the impact of BRI on innovation is not only highly valuable for academic research but also critically important in practical terms.

The contribution of this paper is twofold:

(1) It makes valuable additions to the research on the relationship between BRI and innovation. Building on existing research (Huang, 2016), this paper further expands and deepens the understanding of the relationship between BRI and innovation, thoroughly exploring how BRI directly promotes the allocation of innovation resources and the enhancement of innovation. This multi-dimensional analytical framework offers a more comprehensive and in-depth theoretical perspective for studying the relationship between BRI and innovation, laying a solid foundation for subsequent research.

(2) It expands the research path on the policy effects and strategic opportunities of BRI (Li *et al.*, 2023; Li *et al.*, 2022a; Li *et al.*, 2022b).

This paper not only analyzes the direct impact of BRI on firms' innovation but, more importantly, reveals the internal mechanisms of BRI, providing a new path for understanding and assessing its overall policy effects and strategic opportunities. Specifically, the paper highlights how BRI alleviates firms' financing constraints and intensifies industry competition, thereby contributing to the overall enhancement of firms' innovation. This research path not only helps grasp the far-reaching impact of BRI more comprehensively but also offers policymakers richer policy tools and strategic options to better achieve BRI's ambitious goals.

The remainder of this article is organized as follows. Section 2 reviews the literature on BRI and innovation, Section 3 details the research hypotheses, Section 4 outlines the variables and research methods, Section 5 provides the results of the empirical analysis, discusses the results and further analyzes the content of the study, Section 6 summarizes the research conclusions.

2. Literature review

At the critical juncture of China's economic transformation and industrial upgrading, the BRI not only carries a significant historical mission but also precisely addresses the urgent needs of current and future development. It has become a powerful engine driving the reshaping of China's and the global economic landscape (Huang, 2016). Currently, as BRI continues to be implemented in-depth, its economic and innovation benefits are being unleashed at an unprecedented pace. This initiative greatly enhances infrastructure connectivity across nations, accelerates the free flow of trade and capital and opens up vast new opportunities for technological innovation and industrial collaboration (Chen, 2023).

Extensive research at both national and provincial levels has thoroughly demonstrated the positive role and profound impact of BRI in promoting economic and innovation benefits (Wang and Cheng, 2024; Senadjki *et al.*, 2022; Wu and Si, 2022). As the initiative continues to deepen and expand, academic research perspectives are further refining, with a focus on its multidimensional and profound impact. Specifically, BRI has become a crucial driving force for Chinese cities to deepen international cooperation, expand export markets and optimize export structures. It also acts as a catalyst, stimulating enterprises to embrace transformation and upgrading, thereby encouraging them to implement innovation-driven strategies and achieve leapfrog development in the context of globalization (Xiao *et al.*, 2018; Yu, 2022). This dual effect has spurred in-depth thinking and extensive discussion on how BRI specifically shapes the pattern of regional economic development and guides the trajectory of corporate globalization.

For instance, using a complex network analysis, Lyu *et al.* found that BRI played a pivotal role in enhancing the overall innovation capacity of cities along its route (Lyu *et al.*, 2024). Wang and Chen innovatively applied a two-machine learning model to explore the extensive impact of BRI on the corporate green transition process (Wang and Pang, 2024), highlighting the initiative's remarkable effectiveness in promoting corporations' transition to green and sustainable practices.

A profound and close connection exists between BRI and innovation, with innovation serving as a key driver in this grand initiative, injecting strong impetus into its implementation. Concurrently, BRI provides a valuable opportunity and a practical platform for innovation, enabling a wide range of novel ideas and technologies to be tested and refined in practice (Wang and Lu, 2019; Liu *et al.*, 2023). Consequently, BRI's role in fostering innovation has garnered extensive academic attention and spurred in-depth discussion, despite earlier studies predominantly focusing on inter-provincial or inter-industry innovation capabilities and impacts from a macro perspective (Ju *et al.*, 2013). In recent years, scholars have gradually shifted their research methods, increasingly using firm-level data for their analyses – a transition that has yielded more nuanced and specific studies (Wang *et al.*, 2022). However, direct research on the impact of BRI on firms' innovation capabilities remains scarce, with much of the discussion centered around macro-level analyses of how BRI influences regional innovation.

Existing research presents two main perspectives: the first mainstream view tends to affirm BRI's positive effect, believing that it positively influences innovation activities. Specifically, the initiative has effectively bolstered regional innovation infrastructure and

capacity through cross-border cooperation in regional import and export trade, leveraging cultural diversity's unique strengths and injecting strong impetus into regional innovation development (Xiang *et al.*, 2022). The second perspective argues that BRI primarily acts as a disincentive to innovation. The long payback period and relatively low return on investment in infrastructure projects, combined with resistance from some countries along the routes, may introduce a series of complex risks. These risks could inhibit financial investment in R&D activities in the long run, thereby posing an obstacle to enhancing innovation capacity (Brem and Nylund, 2021). However, this perspective also highlights a crucial turning point: as regions along BRI become more politically stable, economically prosperous and legally robust, their positive contribution to innovation is expected to increase significantly, thereby opening up broader opportunities for future innovation cooperation and development (Kong *et al.*, 2021).

In summary, while the exploration of the relationship between BRI and innovation has begun to take shape, several gaps remain. First, research directly linking BRI to innovation is relatively scarce; and second, investigations into the intrinsic mechanisms of BRI are often fragmented and uncoordinated. Most existing studies focus on analyzing the direct impact of economic and social activities, such as import and export trade, on innovation from a single perspective, often limited to economic and trade cooperation among countries and regions along BRI. However, such an analytical framework often neglects the core endogenous drivers of innovation. A comprehensive examination of BRI's policy effects and strategic opportunities requires integrating perspectives on enterprise financing and human capital.

3. Research hypothesis

Since its inception, the BRI has emerged as a crucial platform for Sino-foreign economic cooperation, with the aim of fostering economic development and collaboration among countries along its route. In this context, innovation capacity, as the cornerstone of economic activities, is directly linked to the success and quality of BRI (Cao *et al.*, 2023).

On one hand, BRI not only provides a broader international platform for enterprises but also promotes the optimal allocation of resources and the expansion of international markets, thereby stimulating the vitality and innovation capacity of enterprises (Rajapathirana and Hui, 2018). Concurrently, infrastructure projects such as transportation and energy pipelines under BRI not only promote economic development in the countries along the route but also create strong market demand and application scenarios for technological innovation in Chinese enterprises.

On the other hand, BRI has effectively alleviated the financial and resource constraints faced by enterprises in their innovation processes through government subsidies, financing facilitation and other policy guidance and support, thereby providing a solid foundation for innovation and offering new opportunities and pathways for enterprises to achieve high-level innovation in the context of globalization (Zhang *et al.*, 2021).

In summary, BRI plays a pivotal role in enhancing innovation capacity and will bring about a more sustainable and efficient development model for enterprises. Based on the above analyses, this paper proposes the following *H1*:

H1. The belt and road initiative enhances firms' innovation capacity.

The internal logic of BRI in promoting innovation enhancement is profound and multidimensional, with the core being the effective alleviation of financing bottlenecks and the promotion of optimal human capital allocation and flow, thereby injecting strong impetus for innovation.

First, in optimizing the financing environment, BRI leverages the dual forces of policy guidance and financial support to significantly reduce the difficulty and cost of financing for participating enterprises. The government and financial institutions have proactively acted to directly reduce enterprises' financial burdens and effectively alleviate their financing constraints through a series of preferential policies, such as broadening bank credit channels, implementing preferential lending rates and providing tax reductions and exemptions (Cai *et al.*, 2023).

This initiative provides enterprises with solid financial backing for their innovation activities, enabling them to invest more confidently in high-risk, long-cycle technology research and development, product innovation and market expansion, thereby accelerating the enhancement of their technological innovation capability (Yu *et al.*, 2021).

Second, BRI also facilitates the flow and optimal allocation of human capital. It not only breaks down geographical boundaries and facilitates the free flow and efficient allocation of valuable human resources, such as highly skilled personnel and academic elites, on a global scale, but also brings advanced knowledge, cutting-edge technology and rich experience, which nourish the innovative soil of enterprises and become an indispensable and vital source of their innovative activities (Li *et al.*, 2021). Concurrently, the initiative has also actively built cooperation platforms, introduced relevant policies and provided incentives for enterprises to increase investment in human capital, thereby building a more complete talent management system and further consolidating the talent base for innovation (Feng *et al.*, 2022).

In summary, through its unique dual mechanism, BRI not only removes obstacles to innovation at the level of enterprise financing but also injects fresh impetus into talent development, collectively promoting the overall enhancement of innovation. Therefore, based on the above analyses, this paper proposes the following *H2* and *H3*:

H2. The belt and road initiative can enhance firms' innovation capacity by alleviating financing constraints.

H3. The belt and road initiative can enhance firms' innovation capacity by strengthening human capital.

In exploring the complex and intertwined dynamics between market structure and BRI, scholars have gradually reached a consensus that a well-designed, well-regulated and orderly industry competition environment is the core driving force to stimulate the innovation energy of enterprises and accelerate the innovation cycle. Specifically, industry competition, as an indispensable component of the market mechanism, plays a decisive role in amplifying the innovation incentive effect under BRI (Bastos, 2020). Therefore, in the process of advancing BRI, the intensity of industry competition exhibits a "double-edged sword" characteristic, both promoting and inhibiting the enhancement of innovation (Cheng *et al.*, 2023).

Only by controlling the intensity of industry competition within a reasonable range can we maximize the innovation potential of enterprises and enhance their innovation under BRI (Cheng *et al.*, 2023). At the same time, information asymmetry – a major obstacle to cross-border investment and innovation cooperation – greatly limits the efficiency of strategic decision-making and the pace of innovation under BRI (Chen *et al.*, 2024). However, BRI is committed to building a comprehensive information-sharing network and policy support framework, which effectively enhances policy transparency, facilitates infrastructure connectivity and strengthens the financial support system. This approach provides enterprises with richer and more accurate market and investment intelligence, significantly reducing decision-making bias and innovation risks due to asymmetric information.

This positive change has significantly contributed to the enhancement of innovation through mechanisms such as economies of scale and reverse technology spillovers. Based on the above analyses, this paper proposes the following *H4* and *H5*:

H4. The degree of industry competition positively moderates the relationship between the belt and road initiative and firms' innovation capacity.

H5. The degree of information asymmetry negatively moderates the relationship between the belt and road initiative and firms' innovation capacity.

4. Model specification and variables

4.1 Research model

This paper examines the specific effects of the BRI on innovation by comparing systematic differences between pilot and non-pilot firms before and after its implementation. Before adopting the difference-in-differences (DID) model, this paper must satisfy the critical assumption of the parallel trend test. That is, there should be no significant difference or common growth trend in the innovation capacity of pilot firms (treatment group) and non-pilot firms (control group) before the implementation of the initiative, but a significant divergence should occur after the implementation of BRI. Based on event study methodology, this paper sets up the following model:

$$Inno_{i,t} = \alpha_0 + \sum_{k=-4}^{k=4} \pi_k Treat_i \times Post_t^k (k \neq -1) + \sum_i \alpha_i X_{i,t} + Year + Firm + \varepsilon_{i,t} \quad (1)$$

where $\text{Inno}_{\text{i,t}}$ represents the innovation capacity of firm i in year t. $\text{Treat}_\text{i} \times \text{Post}_t^k$ indicates whether firm i implemented BRI in year t. $k < 0$ indicates the number of years before the initiative, and $k > 0$ indicates the number of years after the initiative. If there are more than four years before or after the initiative, they are all attributed to year 4 in this analysis. The base period used in this paper is year 1 prior to the implementation of the initiative. Xi,t represents control variables that affect a firm's innovation capacity. To avoid endogeneity, year and firm fixed effects are controlled for, accounting for time and firm-specific effects, respectively. $\varepsilon_{i,t}$ represents the random error term. In equation (1), π_k is the estimated coefficient, which is the focal point of this paper. If π_k is not significant before the implementation of BRI but becomes significant after the initiative, the parallel trend test is satisfied.

After passing the parallel trend test and drawing on the work of Beck *et al.*, this paper constructs the following benchmark model:

$$Inno_{i,t} = \beta_0 + \beta_1 Treat_i \times Post_t + \sum_i \beta_i X_{i,t} + Year + Firm + \varepsilon_{i,t} \quad (2)$$

The estimated coefficient β_1 before $Treat_i \times Post_t$ in equation (2) reflects the net effect of BRI on innovation capacity. If β_1 is significantly positive, it indicates that BRI can significantly improve innovation capacity.

4.2 Variable measurement

4.2.1 Explained variable: firm innovation capacity (Inno). Patent data are widely used to evaluate technological innovation levels in current research (Wang *et al.*, 2023b). This paper uses patent application data to measure innovation capacity. Specifically, patent application data for listed enterprises were obtained from the state intellectual property office of China.

Patent applications were chosen because they allow for a more timely examination of BRI's impact on innovation capacity compared to patent grant data. In this paper, the natural logarithm of patent applications plus one (Inno) is used as a proxy for the dependent variable (Huang, 2016). In subsequent robustness tests, this paper further measures firms' innovation capability from the perspectives of innovation investment and patent grants.

4.2.2 Explanatory variables: belt and road initiative (treat × post). As an important international cooperation framework, BRI aims to achieve a "win-win" situation among countries along its route through infrastructure construction, economic cooperation and exchange (Li *et al.*, 2023). Although BRI was proposed as early as 2013, it became China's official top-level strategy in 2014. Therefore, based on the implementation timeline of the initiative, this paper constructs a dummy variable for the pilot year (Post). If the sample firms are in 2014 or later, Post is set to 1; otherwise, it is set to 0.

Following Cai *et al.* (2023), firms listed in the Directory of Outward Investment Enterprises and investing in countries along the BRI route are classified as the treatment group. First, the names of Chinese listed companies are obtained from the Directory of Outward Investment Enterprises (Institutions) published on the Ministry of Commerce of China's website and compared with listed company data. Second, firms listed in the Directory of Outward Investment Enterprises and investing in countries along the BRI route are classified into the treatment group, while listed firms not involved in outward foreign direct investment are classified into the control group. That is, a dummy variable for pilot enterprises (Treat) is set in addition to Post. If a listed firm is in the Directory of Outward Investment Enterprises and invests in BRI countries (treatment group), Treat is set to 1; otherwise, it is set to 0. In this paper, the interaction term of Post and Treat (Treat × Post) represents the effect of BRI implementation.

4.2.3 Control variable. To mitigate endogeneity problems caused by omitted variables, this paper introduces control variables related to innovation capacity. First, the interaction between firm size and innovation capacity cannot be ignored. For example, Chen argues that in the information and electronics industry, green core competencies exhibit a clear scale advantage (Chen, 2008). In addition, older firms are more resilient to external risks (Ng *et al.*, 1999) and benefit more from innovation (Asad *et al.*, 2024). This paper controls for firm size (Size) and firm age (Age). Second, there is also a close relationship between solvency, cash flow and innovation capacity. Weaker solvency makes creditors less secure in granting loans. Cash flow, as a necessary overhead for daily business operations, is closely related to a firm's operational risk. This paper further controls for financial leverage (Lev) and net operating cash flow (Cflow). In terms of asset composition, a higher proportion of intangible assets to total assets indicates a greater value of technology and goodwill represented by the firm. This is crucial for firms in carrying out technological innovation activities. This paper uses the intangible asset ratio (Itang) to illustrate this point. Furthermore, firm performance is usually inseparable from technological advancements (Chen and Luo, 2024; Pástor and Pietro, 2003). This paper also includes the return on assets and the growth rate of total assets (Tagr). The concentration of shareholder ownership reflects the strategic decision-making ability of the firm's executives, which is closely related to the implementation of innovation strategy. In this paper, equity concentration (Shrcr) is used as a measure. Specific variable definitions and descriptive statistics are provided in Table 1.

5. Empirical analysis

5.1 Parallel trend test

Based on equation (1) from the previous section, the results of the parallel trend test are presented in Figure 1. On the left side of the dashed line, the confidence intervals for the

Table 1. Variable definitions and descriptive statistics

Variable	Variable name	Variable definition	*N*	Mean	Std	Min.	Max.
Inno	Enterprise innovation capacity	Natural logarithmic value of a firm's patent filings plus 1	25,004	2.4583	1.8216	0.0000	7.0000
Treat	Pilot firms	When the listed company is in the Directory of Outward Investment Enterprises and invests in BRI countries, Treat = 1; else Treat = 0	25,004	0.1496	0.3567	0.0000	1.0000
Post	Policy time	When the year in which the sample of firms is located is in 2014 and later years, *Post* = 1, else Treat = 0。	25,004	0.6919	0.4617	0.0000	1.0000
Treat × *Post*	Belt and road initiative	Interaction terms for *treat and post*	25,004	0.1069	0.3090	0.0000	1.0000
Size	Firm size	Natural logarithm of total enterprise assets	25,004	22.1774	1.3360	19.4857	26.2652
Age	Firm age	Natural logarithm of the difference between the current year and the year of listing	25,004	2.2384	0.8200	0.0000	3.3322
Lev	Financial leverage	Ratio of total liabilities to total assets of the enterprise	25,004	0.4415	0.2145	0.0505	0.9715
Cflow	Net cash flow from operations	Net cash flow from operating activities to total assets	25,004	0.0450	0.1186	−11.0562	2.4573
Itang	Intangible assets	Ratio of net intangible assets to total assets	25,004	0.0474	0.0540	0.0000	0.3466
Roa	Profitability of total assets	Ratio of net profit to average total assets	25,004	0.0299	0.0353	0.0646	−0.2792
Tagr	Total asset growth rate	Ratio of growth in total assets of the enterprise at the end of the year to total assets at the beginning of the year	25,004	0.1228	0.0851	0.8884	−0.9613
Shrcr	Shareholding concentration	Concentration of shareholdings of top five shareholders	25,004	0.4973	0.4894	0.2017	0.2147

Source(s): Table by authors

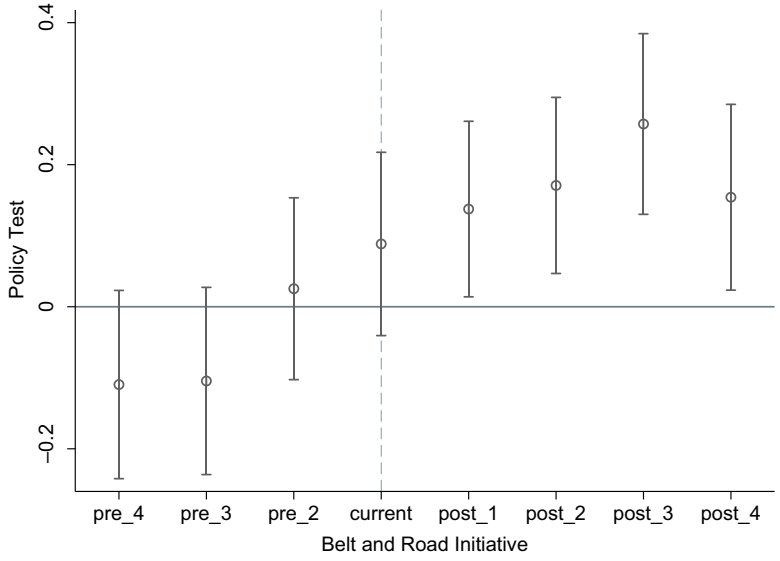

Figure 1. Parallel trend test
Source(s): Figure by authors

estimated coefficients all include 0, indicating no significant difference in the innovation capacity between the treatment and control groups before the implementation of BRI. However, after the implementation of the policy, the difference becomes significant, consistent with the parallel trend hypothesis, thereby passing the parallel trend test.

5.2 Baseline results

Table 2 presents the baseline regression results based on equation (2). Column (1) reports the regression results without control variables. The estimated coefficient of Treat × Post is significantly positive at the 1% level. This preliminary result suggests that BRI significantly enhances the technological innovation level of publicly traded firms. Columns (2) to (9) present the regression results with the stepwise inclusion of firm-level control variables. The study's results indicate that BRI stimulates firms to engage in innovation activities, irrespective of the inclusion of control variables, thereby enhancing innovation capacity and verifying *H1*. This is consistent with the findings of Huang H.B. *et al.*, which suggest that countries along the BRI can effectively promote collaborative innovation between Chinese publicly traded firms and countries along the BRI route by enhancing the intermingling of factor flows and reducing the costs of cross-border collaboration (Huang *et al.*, 2024). Therefore, under BRI, both Chinese and foreign enterprises can leverage the abundant resources and factors along the routes to achieve a mutually beneficial "win-win" situation.

5.3 Robustness test

5.3.1 Propensity score matching (PSM). This paper divides publicly traded firms into treatment and control groups based on the policy guidelines from China's Ministry of Commerce. The selection of pilot firms may not be random, making it impossible to ensure that pilot and non-pilot firms have identical characteristics. To mitigate potential endogeneity

Table 2. Baseline regression

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treat × *Post*	0.1968*** (0.0389)	0.1465*** (0.0377)	0.1435*** (0.0377)	0.1444*** (0.0377)	0.1439*** (0.0377)	0.1431*** (0.0377)	0.1423*** (0.0377)	0.1427*** (0.0377)	0.1420*** (0.0377)
Size		0.4492*** (0.0153)	0.4464*** (0.0155)	0.4493*** (0.0158)	0.4504*** (0.0158)	0.4513*** (0.0158)	0.4558*** (0.0160)	0.4515*** (0.0161)	0.4481*** (0.0162)
Age			0.0335 (0.0221)	0.0401* (0.0231)	0.0409* (0.0231)	0.0347 (0.0231)	0.0270 (0.0236)	0.0289 (0.0236)	0.0342 (0.0238)
Lev				−0.0595 (0.0605)	−0.0645 (0.0606)	−0.0715 (0.0606)	−0.0708 (0.0607)	−0.0270 (0.0634)	−0.0128 (0.0636)
Cflow					−0.0776* (0.0414)	−0.0850** (0.0413)	−0.0853** (0.0414)	−0.1022** (0.0424)	−0.0976** (0.0423)
Itang						0.8097*** (0.2312)	0.7885*** (0.2318)	0.8155*** (0.2317)	0.8066*** (0.2317)
Roa							−0.0169 (0.0118)	−0.0183 (0.0120)	−0.0187 (0.0121)
Tagr								0.2819** (0.1231)	0.2822** (0.1230)
Shrcr									−0.1386** (0.0645)
cons	2.4373*** (0.0073)	−7.5185*** (0.3392)	−7.5313*** (0.3382)	−7.5857*** (0.3424)	−7.6065*** (0.3429)	−7.6474*** (0.3426)	−7.7255*** (0.3449)	−7.6644*** (0.3453)	−7.5332*** (0.3510)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	25,004	25,004	25,004	25,004	25,004	25,004	25,004	25,004	25,004
R^2	0.7652	0.7772	0.7773	0.7773	0.7773	0.7775	0.7775	0.7776	0.7776

Note(s): ***, ** and * represent significance at the 1, 5 and 10% levels, respectively. Robust standard errors are in parentheses
Source(s): Table by authors

issues, propensity score matching (PSM) was conducted before implementing the multi-period DID approach (Heckman *et al.*, 1997). Covariates in the PSM process were defined based on firm-level control variables from the benchmark model. One-to-one nearest neighbor matching was used to pair the treatment and control groups. As shown in column (1) of Table 2, the average treatment effect from PSM is 15.25, and the estimated coefficient of Treat × Post is significantly positive at the 1% level. As the balance test in Figure 2 shows, the standardized deviations of all covariates are less than 10% and are significantly smaller than the standardized deviations before matching. According to the *t*-test, there is no significant difference between the matched samples of the two groups in terms of the matching variables, indicating that the treatment and control group samples are balanced. The regression results after radius matching are shown in column (2), where the significance and magnitude of the estimated coefficient align perfectly with the nearest-neighbor matching results, further demonstrating the robustness of the findings.

5.3.2 Substitution of explanatory variables. In the benchmark model, this paper measures firm innovation capability using patent applications. To account for the potential impact of different measures on the findings, the explanatory variables were substituted. On the one hand, from the perspective of innovation inputs, R&D expenditures reflect the amount firms invest in innovation activities each year. The natural logarithm of R&D expenditures is used to characterize firms' innovativeness (Inno1). On the other hand, patent grants reflect the substantive output of innovation, and the natural logarithm of patent grants plus one is used to measure firms' innovation capacity (Inno2). Columns (3) and (4) of Table 3 show that BRI significantly enhances firms' innovation capacity, regardless of the proxies used for measuring firms' innovation capabilities.

5.3.3 Placebo test. A placebo test within a "counterfactual" framework was conducted to exclude the effect of random perturbations. First, the timing of BRI implementation was randomized for each pilot enterprise. Second, 266 pilot firms were randomly selected to

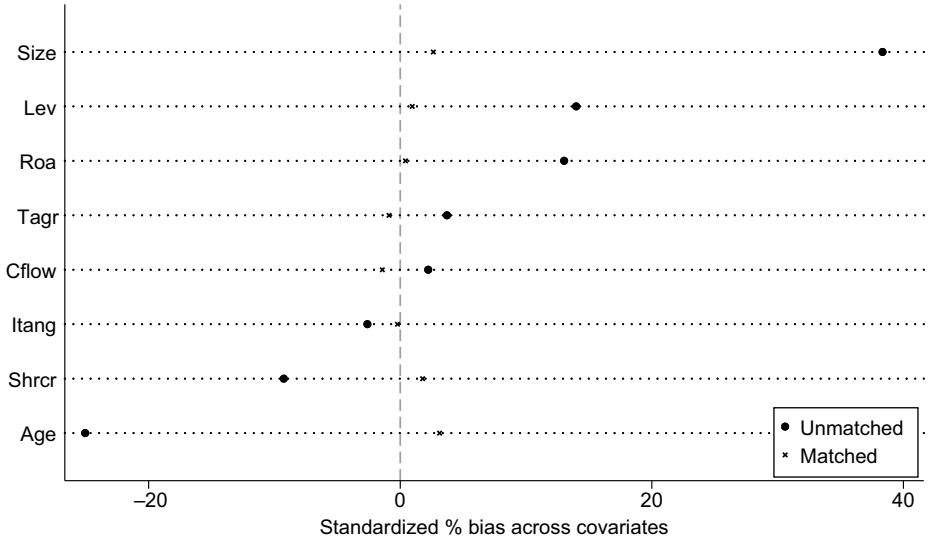

Figure 2. Matching balance test
Source(s): Figure by authors

Table 3. Robustness test

Variable	PSM (1)	PSM (2)	Substitution of explanatory variables (3)	Substitution of explanatory variables (4)
Treat × *Post*	0.1389*** (0.0377)	0.1389*** (0.0377)	0.0896*** (0.0346)	0.1923*** (0.0369)
Size	0.4576*** (0.0163)	0.4576*** (0.0163)	0.8233*** (0.0194)	0.3901*** (0.0151)
Age	0.0143 (0.0238)	0.0143 (0.0238)	−0.2470*** (0.0223)	0.0170 (0.0222)
Lev	0.0023 (0.0638)	0.0023 (0.0638)	−0.3406*** (0.0687)	0.0705 (0.0591)
Cflow	−0.1099** (0.0437)	−0.1099** (0.0437)	0.4153*** (0.1101)	−0.1259*** (0.0452)
Itang	0.8037*** (0.2331)	0.8037*** (0.2331)	0.2866 (0.2900)	1.1888*** (0.2240)
Roa	−0.0607*** (0.0119)	−0.0607*** (0.0119)	−0.0818*** (0.0205)	−0.0150 (0.0101)
Tagr	0.3350*** (0.1244)	0.3350*** (0.1244)	0.4659*** (0.1273)	−0.0883 (0.1164)
Shrcr	−0.1446** (0.0646)	−0.1446** (0.0646)	−0.2342*** (0.0647)	−0.1466** (0.0607)
cons	−7.6953*** (0.3521)	−7.6953*** (0.3521)	0.1729 (0.4150)	−6.4849*** (0.3285)
Year	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes
N	24,978	24,978	20,139	25,004
R^2	0.7777	0.7777	0.8623	0.7821

Note(s): ***, ** and * represent significance at the 1, 5 and 10% levels, respectively. Robust standard errors are in parentheses
Source(s): Table by authors

serve as the treatment group, while the remaining firms served as the control group. A new policy shock variable was constructed by forming an interaction term between the newly created dummy variable for pilot firms and the dummy variable for policy timing. After 500 iterations, the placebo test results are shown in Figure 3. The estimated coefficients for the

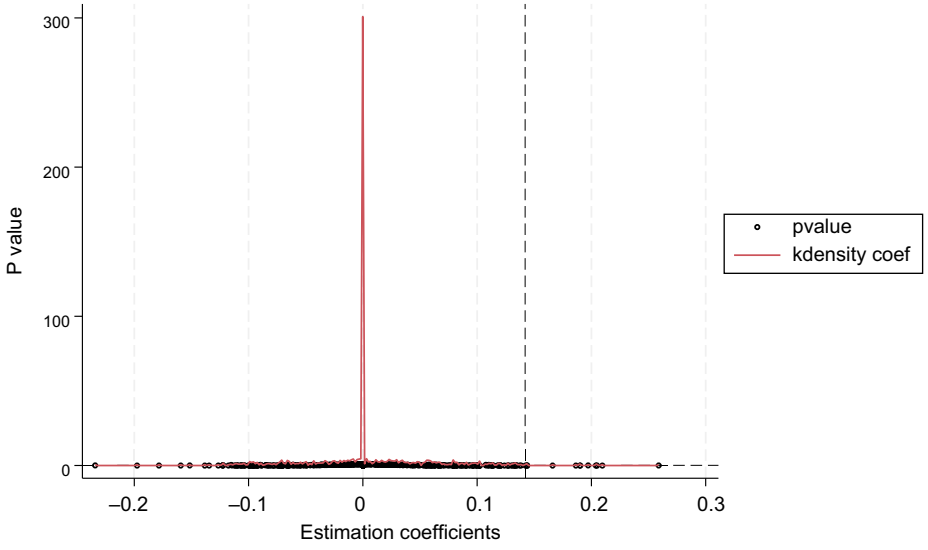

Figure 3. Placebo test
Note(s): Solid lines represent kernel density curves, dots represent *p*-values and dashed lines represent the true regression coefficients
Source(s): Figure by authors

dummy policy variables are clustered around 0, and most are insignificant. The true value of 0.1420 is significantly different from the estimates in the placebo test, indicating a low-probability event. It is unlikely that BRI's estimated effect on firms' innovation capacity is driven by unobserved chance factors.

5.4 Other robustness tests

5.4.1 Controlling for concurrent policy interventions. Concurrent with BRI, China has implemented several significant policies that could potentially impact firms' innovation capacity. This may introduce competing hypotheses for the baseline regression results, necessitating further control for three significant confounding policies that may have been present during the sample period. From a transnational policy perspective, as an emerging foreign trade model, the comprehensive pilot zones for cross-border e-commerce provide new impetus for improving innovation capacity (Ren *et al.*, 2023). This policy promotes the clustering of high-end productive service industries, such as information transmission, software and information technology services, thereby nurturing innovative vitality (Li *et al.*, 2022b).

From a digital economy perspective, as the digital wave sweeps across the globe, countries have begun promoting digital transformation centered on 5G, big data, artificial intelligence and related technologies. Studies have shown that the use of digital technology is conducive to the renewal of energy sources and technologies (Hervas-Oliver *et al.*, 2021; Lyu *et al.*, 2024). This paper constructs dummy variables for the comprehensive pilot zone for cross-border e-commerce, the broadband China policy, the gigabit city initiative and the national-level comprehensive pilot zone for big data, which are then included in equation (2) for regression analysis. Columns (1) and (2) of Table 4 report the results after excluding other policy interventions. Column (1) presents the regression results controlling only for the comprehensive pilot zone for cross-border e-commerce. At this point, the estimated coefficients of the core explanatory variables are significantly positive at the 1% significance level. When further controlling for digital technology policies, BRI continues to significantly enhance innovation capacity. This suggests that the above policies have not confounded the findings of this paper.

5.4.2 Inclusion of missing variables. This paper accounts for the importance of economic development level, local industry tier and urbanization level in fostering technological innovation (Xu *et al.*, 2013; Gao and Lu, 2023). This paper controls for the natural logarithm of city-level GDP per capita, the ratio of secondary and tertiary sector output to GDP, and the ratio of urban resident population to total population. On the other hand, innovation activities cannot be sustained without financial transactions (Walker *et al.*, 2015). This paper controls for the degree of local financial development and considers the impact of foreign investment levels on technological innovation (Walker *et al.*, 2015). The degree of financial development is measured by the ratio of year-end financial institutions' deposit and loan balances to regional GDP, while the level of foreign investment is measured by the ratio of actual used foreign capital to regional GDP. The estimated coefficients in column (3) of Table 4 show that BRI significantly enhances firms' innovation capacity, regardless of whether urban variables are controlled for.

5.4.3 Inclusion of fixed effects. Given that other influences at the city and industry levels may bias the results, this paper further controls for city and industry fixed effects. Column (4) of Table 4 presents the regression results with the inclusion of fixed effects. The findings remain robust and reliable after controlling for random shocks at the city or industry level.

5.4.4 Controlling for exogenous shocks. The financial crisis that erupted in 2008 caused turmoil in global financial markets and a downturn in the real economy, significantly

Table 4. Other robustness tests

Variable	Exclusion of contemporaneous policies (1)	(2)	Addition of missing variables (3)	Increase fixed effects (4)	Exclusion of exogenous shocks (5)	(6)
Treat × *Post*	0.1317*** (0.0397)	0.1360*** (0.0406)	0.1557*** (0.0383)	0.1074*** (0.0380)	0.1201*** (0.0426)	0.1876*** (0.0380)
Size	0.4579*** (0.0175)	0.4619*** (0.0178)	0.4496*** (0.0168)	0.4844*** (0.0167)	0.4809*** (0.0187)	0.4080*** (0.0193)
Age	0.0316 (0.0245)	0.0288 (0.0247)	0.0470* (0.0242)	0.0275 (0.0241)	−0.0084 (0.0265)	0.0937*** (0.0273)
Lev	−0.0287 (0.0673)	−0.0242 (0.0681)	−0.0227 (0.0656)	−0.0615 (0.0637)	−0.0794 (0.0719)	0.1229* (0.0722)
Cflow	−0.1004** (0.0426)	−0.1012** (0.0427)	−0.0920** (0.0421)	−0.0460 (0.0481)	−0.1394* (0.0787)	−0.0956** (0.0405)
Itang	0.8383*** (0.2477)	0.8532*** (0.2505)	0.8258*** (0.2366)	0.8310*** (0.2352)	0.7265*** (0.2678)	0.5546** (0.2635)
Roa	−0.0167 (0.0121)	−0.0143 (0.0119)	−0.0174 (0.0120)	−0.0234* (0.0136)	−0.0142 (0.0121)	−0.0150 (0.0127)
Tagr	0.2324* (0.1281)	0.2139* (0.1293)	0.2854** (0.1251)	0.2207* (0.1218)	0.2093 (0.1344)	0.2995** (0.1434)
Shrcr	−0.1152* (0.0669)	−0.1282* (0.0678)	−0.1487** (0.0662)	−0.1091* (0.0647)	−0.0675 (0.0699)	−0.1412* (0.0743)
Comprehensive pilot zone for cross-border E-commerce	Yes	Yes	No	No	No	No
Broadband China policy	No	Yes	No	No	No	No
Gigabit city construction	No	Yes	No	No	No	No
National-level comprehensive pilot zone	No	Yes	No	No	No	No
Urban omitted variables	No	No	Yes	No	No	No
City/industry fixed	No	No	No	Yes	No	No
cons	−7.7106*** (0.3790)	−7.7707*** (0.3855)	−8.3196*** (0.7071)	−8.3097*** (0.3613)	−8.0819*** (0.4064)	−6.9379*** (0.4175)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes
N	23,805	23,437	24,023	24,883	22,394	20087
R^2	0.7813	0.7816	0.7790	0.7825	0.7866	0.7883

Note(s): ***, ** and * represent significance at the 1, 5 and 10% levels, respectively. Robust standard errors are in parentheses
Source(s): Table by authors

Table 5. Intermediary mechanism test

Variable	(1) FC	(2) SA	(3) PostGra	(4) UnderGra	(5) R&DStaff
Treat × *Post*	−0.0127*** (0.0041)	−0.0518*** (0.0030)	0.4792*** (0.1297)	−0.3686 (0.3444)	12.6712*** (4.0778)
Size	−0.1523*** (0.0028)	0.0329*** (0.0024)	0.2374** (0.0976)	1.5861*** (0.2103)	0.1036 (0.2184)
Age	−0.0833*** (0.0038)	0.0471*** (0.0020)	−0.2890*** (0.0915)	−1.2325*** (0.2152)	−0.2757 (0.2561)
Lev	−0.3468*** (0.0121)	−0.0632*** (0.0080)	−1.2678*** (0.3650)	−2.5866*** (0.7759)	−3.1237*** (0.7337)
Cflow	−0.0564*** (0.0175)	0.0570*** (0.0110)	−0.6147* (0.3569)	−3.0112*** (1.1485)	0.4746 (0.9404)
Itang	−0.0626* (0.0356)	−0.0428 (0.0279)	−3.0193*** (1.0855)	−17.1704*** (3.1170)	−3.2266 (3.0563)
Roa	0.0009 (0.0019)	0.0035** (0.0014)	0.0165 (0.0311)	−0.0168 (0.1170)	−0.1793 (0.1433)
Tagr	0.3020*** (0.0229)	0.0135 (0.0150)	−0.8591 (0.5363)	0.3250 (1.3917)	−2.7155** (1.1165)
Shrcr	0.0190** (0.0081)	0.0275*** (0.0060)	−0.8208*** (0.2608)	−1.9129*** (0.6541)	−0.5287 (0.6635)
cons	4.1935*** (0.0598)	2.9725*** (0.0517)	0.9506 (2.0603)	−4.0835 (4.5436)	13.4691*** (4.7913)
Year	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes
N	22,315	24,473	16,034	20,292	12,604
R^2	0.8784	0.9444	0.8594	0.8721	0.9036

Note(s): ***, ** and * represent significance at the 1, 5 and 10% levels, respectively. Robust standard errors are in parentheses
Source(s): Table by authors

affecting China's financial institutions and listed companies. To exclude the subsequent impacts of the financial crisis (as we believe financial markets remain affected for up to two years post-crisis) and considering the significant impact of the COVID-19 pandemic at the end of 2019 on the national economy, sample years 2020 and beyond are removed. Columns (5) and (6) of Table 4 report the estimation results after excluding exogenous shocks. The estimated coefficients show that BRI continues to significantly stimulate innovation capacity, regardless of whether the financial crisis or the COVID-19 pandemic is excluded.

5.5 Further analysis

5.5.1 Mediation effect test. According to Schumpeter's theory of innovation, technological innovation, as a key driver of economic development, primarily involves the recombination of factors of production by entrepreneurs.

First, given the high risk and long lead times associated with innovation, such activities often require sustained financial support (Wu *et al.*, 2022). Under the theory of financial repression, inherent market imperfections, such as information asymmetry, often lead to financing constraints for most firms (Xuan and Peng, 2022). The implementation of BRI can effectively alleviate these constraints. On one hand, institutions such as the Silk Road Fund and the Asian Infrastructure Investment Bank facilitate financial support and services for the external operations of pilot enterprises. These institutions can effectively address capital shortages and mitigate risks. On the other hand, enterprises participating in BRI have more accessible channels for project investment and financing support. The Chinese Government offers strategic support for enterprises' international operations through export credit and insurance services, while some local governments provide additional support through policy incentives or tax breaks for participating in economic and trade cooperation along the BRI routes. The implementation of the Initiative can alleviate financing constraints, providing the necessary financial resources for enterprises to pursue innovative activities and enhance internal technological innovation capacity. Drawing on the work of Fazzari *et al.* and Ju *et al.*, the Financing Constraints Index (FC) and Solvay-Azad Index (SA) indices are used to measure firms' financing constraints (Fazzari *et al.*, 1988; Huang, 2016).

Table 5 reports the mediation mechanism test results based on financing constraints. The estimated coefficients in columns (1) and (2) are significantly negative at the 1% significance level, indicating that BRI has significantly alleviated firms' financing difficulties. In conclusion, BRI can significantly stimulate firms' innovative activities by alleviating financing constraints, confirming *H2*. Indeed, innovation activities are largely constrained by the availability of financing. Particularly for SMEs, firms often choose not to engage in R&D activities to avoid uncertainties like innovation failures (Wang *et al.*, 2023a).

Second, talent is a core driver of innovation and one of the key elements essential to innovation activities (Xiao *et al.*, 2023; Fan *et al.*, 2024). Projects along the routes involving Chinese enterprises require a large number of specialized skills and management personnel. This demand will stimulate the domestic workforce to enhance education and training to meet the need for human capital with technical and professional skills. While promoting economic cooperation, the initiative is also fostering educational and academic exchanges among the countries along the route. Numerous study-abroad exchange programs have been established to promote cross-cultural learning and technology exchanges among talents from different countries. This diversity of cultural backgrounds also enriches China's human capital and provides new momentum for technological innovation. Finally, as infrastructure continues to improve along the route, talent is increasingly mobilized across borders among these countries. Overall, BRI facilitates the cultivation, mobility and cross-border exchange of human capital, playing an important role in guiding innovative activities. The human

capital variables of firms are examined from two perspectives: education and position. At the academic level, workers with graduate and undergraduate degrees possess higher education levels and more extensive scientific research backgrounds compared to less educated workers. This, therefore, provides firms with valuable academic experience. At the positional level, compared to production and marketing personnel, R&D personnel possess greater knowledge and technical skills, which are conducive to providing professional guidance in key technological areas. The greater the availability of the aforementioned human capital, the stronger the enterprise's position in science and technology innovation.

Table 5 presents the mediation mechanism test results based on human capital. The estimated coefficients in columns (3) and (5) are all significantly positive at the 1% significance level. BRI significantly stimulates firms to engage in innovative activities by improving human capital, thereby confirming *H3*. However, the estimated coefficients in column (4) indicate that BRI does not significantly affect the number of employees with a bachelor's degree. This may be because undergraduate education primarily focuses on day-to-day teaching and practical training and has not yet extended to broader academic research activities, as seen in graduate education. Although BRI has helped raise the level of human capital, this effect is more pronounced among employees with postgraduate degrees or higher.

5.5.2 Moderating effect test. Inter-firm decision-making is a long-term dynamic interactive process (Dougal *et al.*, 2015). An enterprise's innovation strategy is often influenced by other firms in the same industry. As competition intensifies, firms are likely to adopt technological innovations to gain unique technological advantages and compete for market share. This is known as the competition avoidance effect, where firms adopt technological innovation to avoid intense market competition (Aghion *et al.*, 2005). Similarly, as BRI significantly boosts firms' innovative activities, more competitive firms within an industry have greater incentives to engage in technological innovation. In other words, the intensity of competition within an industry strengthens the positive relationship between BRI and firms' innovation capacity. The Herfindahl Index (HHI) was used as an indicator of industry competition intensity. The equation is $\mathrm{HHI} = \sum_{j=1}^{n}\left(X_{ij}/\sum_{j=1}^{n}X_{ij}\right)^2$, where X_{ij} represents the current period-end main business revenue of firm i in industry j. The smaller the value, the higher the level of competition in the industry. To ensure robustness, this paper re-measures industry competition using operating income instead of main business income.

Table 6 presents the tests of the moderating mechanism based on industry competition intensity. Columns (1) and (2) show that Treat × Post × HHI_A are both significantly negative at the 5% significance level. This implies that the higher the level of industry competition, the more pronounced the effect of the initiative on firms' innovation capacity.

In addition, according to information asymmetry theory, information is incomplete and unevenly distributed among firms (Haunschild, 1993). For firms at an information disadvantage, both information search costs and strategic decision-making costs are higher (Liu *et al.*, 2024a, 2024b). Therefore, in innovation activities, if a firm's information transparency is low, its absorptive capacity for innovative knowledge and capital is relatively weak, hindering technological change. Although BRI can have an enabling effect, firms in the information trough do not receive the positive signals of the policy and cannot capitalize on this important opportunity. Following the methods of Gul *et al.* (2010) and Xiao *et al.* (2023), this paper uses stock price synchronization as a proxy for information asymmetry.

Table 6. Moderating effect test

Variable	(1) *Inno*	(2) *Inno*	(3) *Inno*
Treat × *Post*	0.2128*** (0.0516)	0.2035*** (0.0524)	0.1780*** (0.0391)
Treat × *Post* × HHI_A	−0.3821** (0.1744)		
Treat × *Post* × HHI_D		−0.3565* (0.2017)	
Treat × *Post* × *SYNCH*			−0.0598** (0.0259)
HHI_A	−0.1081 (0.0672)		
HHI_D		−0.0354 (0.0699)	
SYNCH			−0.0057 (0.0108)
Size	0.4444*** (0.0165)	0.4427*** (0.0164)	0.4270*** (0.0205)
Age	0.0420* (0.0244)	0.0453* (0.0243)	0.0960*** (0.0312)
Lev	−0.0044 (0.0645)	−0.0046 (0.0645)	0.0561 (0.0762)
Cflow	−0.1031** (0.0429)	−0.1046** (0.0431)	−0.0841 (0.0846)
Itang	0.8650*** (0.2359)	0.8385*** (0.2361)	0.6031** (0.2722)
Roa	−0.0194 (0.0125)	−0.0177 (0.0120)	−0.0297** (0.0143)
Tagr	0.2821** (0.1243)	0.2918** (0.1243)	0.2417 (0.1538)
Shrcr	−0.1420** (0.0654)	−0.1403** (0.0653)	−0.1367* (0.0767)
cons	−7.4483*** (0.3577)	−7.4353*** (0.3575)	−7.3298*** (0.4425)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
N	24,329	24,344	19,131
R^2	0.7793	0.7792	0.7923

Note(s): ***, ** and * represent significance at the 1, 5 and 10% levels, respectively. Robust standard errors are in parentheses
Source(s): Table by authors

When stock price synchronization is higher, idiosyncratic information in stock prices is lower, indicating a higher degree of information asymmetry.

The estimated coefficient of Treat × Post × SYNCH in column (3) is significantly negative at the 1% level. This indicates that information asymmetry weakens the effect of BRI on innovation capacity. This confirms the expectation set forth in the previous section. Therefore, information asymmetry can significantly weaken the impact of BRI on enterprise innovation. This is consistent with real-world observations. Compared to enterprises with closed information, listed enterprises with information advantages can access more external resources, sending positive signals to their production and operations.

6. Conclusions

This study explores the effects of BRI on innovation and its underlying mechanisms. The empirical results indicate that BRI significantly incentivizes enterprises to engage in innovative activities. Furthermore, the PSM-DID analysis, substitution of explanatory variables, placebo test, exclusion of contemporaneous policy disturbances and other robustness tests further confirm that BRI has a significant impact on firm innovation.

Further analysis reveals that BRI significantly reduces financing constraints and enhances human capital, thereby increasing firms' innovation capacity. While industry competition intensity significantly strengthens the positive relationship between BRI and firms' innovation capacity, information asymmetry significantly weakens this positive effect.

In summary, policymakers can adopt comprehensive policies similar to BRI within their own countries to promote cross-border technological exchanges and resource sharing, thereby stimulating innovation vitality and enhancing the competitiveness of domestic enterprises. By strengthening the link between the international macroeconomic cycle and the domestic economy, countries can optimize their innovation ecosystems and enhance their overall innovation capacity in the context of globalization.

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Further reading

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