Heliyon 10 (2024) e38457

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Can changes in corporate income tax rate affect corporate innovation?

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ARTICLE INFO

JEL classification:
D21
H25
O32

Keywords:
Corporate income tax rate
Corporate innovation
Market competition

ABSTRACT

The relationship between corporate income tax rates and innovation is a critical international issue. Existing studies often overlook the potential mechanisms of market competition and productivity heterogeneity. This paper addresses these gaps by integrating these elements into a unified mathematical analysis framework. Using China's corporate income tax reform as a quasi-natural experiment, this study empirically tests the model. The findings reveal that decreases in tax rates significantly foster innovation, while increases have the opposite effect. The underlying mechanism involves market competition, with the impact of tax changes being more pronounced in firms with higher productivity. This study deepens the understanding of the nexus between corporate income tax and innovation, providing new insights to refine tax policies that promote innovative economic development globally.

1. Introduction

The adjustment of corporate income tax rates significantly impacts economic dynamics, influencing corporate investment strategies and innovation activities. Prior research underscores innovation's crucial role in driving long-term economic growth and delineates the foundational contributions of tax policies to shaping economic landscapes, highlighting the substantial influences of tax adjustments on both resource allocation and innovative outputs [1–4]. Particularly, China's monumental corporate income tax reform (CITR) in 2008, which standardized tax rates across domestic and foreign entities, provides a unique empirical setting to explore these effects due to its global economic stature and rapid development. This study critically evaluates how CITR influences corporate innovation by dissecting the direct and indirect mechanisms through which tax changes affect firms' operational and strategic behaviors. Leveraging China's 2008 CITR as a quasi-natural experiment, this research not only enhances understanding of the dynamic interactions between tax policies and corporate innovation activities but also informs precise, data-driven policy making to stimulate economic and innovative growth. Through a comprehensive analysis, informed by the empirical data from the CITR [5], this investigation is pivotal for its potential to guide global economic policy, given the scale of China's economy and the extensive implications of its tax reforms.

Previous studies, such as those by Atanassov & Liu (2020) and Akcigit et al. (2022), have extensively explored how changes in corporate income tax rates impact corporate innovation directly, primarily through adjustments in funding and cost structures [6,7].

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https://doi.org/10.1016/j.heliyon.2024.e38457
Received 19 September 2023; Received in revised form 14 September 2024; Accepted 24 September 2024
Available online 25 September 2024

However, these studies have tended to overlook the indirect pathways through which tax policies affect innovation, particularly the mediating role of market dynamics. Additionally, there is a notable gap in understanding how these tax effects vary among firms with different levels of productivity. This oversight forms the basis of our research motivation, leading us to investigate the broader and more nuanced impacts of tax rate changes.

Our study seeks to delve into these lesser-explored areas by asking the following research questions: How do changes in corporate income tax rates indirectly affect innovation through mechanisms such as market competition? Furthermore, how do these tax effects differ among firms across various productivity tiers? By addressing these questions, we aim to provide a more comprehensive view of the dynamics between tax policies and corporate innovation activities, enriching the current economic literature with a deeper analysis of both direct and indirect tax influences.

This study aims to develop a novel theoretical framework to analyze both the direct and indirect effects of changes in corporate income tax rates on corporate innovation. By leveraging the 2008 CITR in China as a quasi-natural experiment, the research will dissect how these tax changes influence innovation differently across firms with varied productivity. The objectives are twofold: firstly, to construct a comprehensive model that integrates market dynamics with tax rate adjustments, and secondly, to empirically assess the differential impacts of these adjustments, providing a robust basis for refining tax policies. Ultimately, this study seeks to equip policymakers with grounded, empirical insights to formulate targeted incentives that foster innovation across the corporate spectrum.

China's 2008 CITR provides a unique natural experiment due to its uniform application across varied economic sectors and geographical areas, making it ideal for analyzing the multifaceted impacts of tax policies on corporate innovation. This reform, significant due to China's substantial role in the global supply chain and its diverse and rapidly evolving economic landscape, offers a distinctive opportunity to study the nuanced effects of fiscal changes in a major world economy. The comprehensive scope of the tax adjustments and China's dynamic market conditions uniquely position this study to contribute valuable insights into the interplay between tax policy and innovation, with implications extending beyond its borders. This choice ensures the findings are not only locally relevant but also globally resonant, providing crucial data for economic policy-making worldwide.

The remainder of the paper is structured as follows: Section 2 reviews the literature and proposes a theoretical model; section 3 describes the research design; section 4 presents various regression results and detailed discussions; finally, the paper concludes with conclusions, policy recommendations, and limitations of the study.

2. Literature review and theoretical hypotheses

2.1. Literature review

2.1.1. The importance of innovation for economic development

Innovation plays a multidimensional and complex role in driving economic development, encompassing critical areas from human capital and tax policies to technological advancements, resource management, intellectual property protection, and entrepreneurial ecosystems. A comprehensive analysis of representative studies in these areas deepens our understanding of how these factors interact and collectively drive economic development and technological innovation.

Regarding tax policy, studies by Atanassov and Liu (2020) [6] have shown that reductions in corporate income tax significantly promote corporate innovation activities, particularly in firms with weak governance and significant financial constraints. Similarly, Akcigit et al. (2022) used long-term data to demonstrate a negative correlation between tax rates and innovation activities, emphasizing the complex impact of tax policies on innovation [7]. Additionally, the application of technological advancements and automation has significantly transformed economic structures and urbanization processes. Research by Li et al. (2020) in Dongguan, China, showed that industrial automation has shifted labor from labor-intensive to technology-intensive sectors, altering both employment structures and urban spatial configurations [8]. Pan et al. (2022) found that the digital economy significantly enhanced the total factor productivity of Chinese provinces, revealing the interactive relationship between technological integration and regional development strategies [9]. Market size and demand conditions also play crucial roles in shaping corporate innovation decisions. Aghion et al. (2022) analyzed how market demand influences firms' patent activities, particularly in companies with higher productivity [10]. Additionally, Kogan et al. (2017) introduced a new method to assess the economic significance of technological innovations through market responses, indicating profound impacts on economic growth and industrial transformation [11]. Grossman and Helpman (1993) emphasized through their models that innovation is a direct result of industrial research investment, providing a theoretical foundation for understanding the innovation-driven global economic growth [12]. Human capital is equally crucial for fostering innovation and economic development. Diebolt and Hippe (2019) utilized historical data to reveal the pivotal role of human capital in regional innovation and economic development [13]. Furthermore, studies by Fang et al. (2023) and Gong et al. (2023) showed that technological innovation positively impacts economic growth and that the decrease in corporate income tax rates significantly enhances firm-level innovation [14,15]. Gyedu et al. (2024) analyzed the impact of intellectual property on economic growth in G20 and developing countries [16], highlighting the importance of intellectual property protection. In terms of digital technology innovation, research by Junarsin et al. (2021) emphasized the potential contributions of financial technology to economic growth [17]. Lee (2020) discussed the interactions between innovation, growth, and distribution in his new economic development theory [18]. Sharma et al. (2023) explored the complementarity between entrepreneurial ecosystems and financial inclusivity [19]. Finally, Zhou et al. (2021) examined how technological innovations and structural transformations drive economic growth in China [20].

Overall, innovation plays a central role in driving global economic growth. Effective policies and strategies must consider a variety of factors such as human capital, tax incentives, resource management, and intellectual property protection to maximize economic development benefits. These complex interactions highlight the diversity and depth that must be considered in formulating innovation policies.

2.1.2. The impact of corporate income tax on technological innovation

Exploring the impact of corporate income tax on technological innovation is a widely researched area, demonstrating how tax policies influence corporate innovation decisions and economic performance from various angles. By integrating these key studies, we can construct a comprehensive perspective on how tax incentives affect corporate innovation.

Initially, research by Akcigit et al. (2022) analyzed tax data from the 20th century in the United States [7], finding that higher personal and corporate tax rates significantly suppress innovation activities, especially in technology-intensive industries. Their studies revealed a close correlation between tax rates and the output and interstate mobility of corporate innovators. Correspondingly, research by Atanassov and Liu (2020) found that significant reductions in corporate income tax markedly encouraged corporate innovation [6], particularly in companies with weak governance structures and significant financial constraints. This effect was further supported in studies by Dechezleprêtre et al. (2023), who found that tax reliefs sustainably increased high-quality patent outputs in companies and their technologically adjacent firms through the regression discontinuity design of R&D tax incentives [21]. Cheng et al. (2021) demonstrated a significant positive correlation between companies' patent activities and tax planning, particularly notable in multinational corporations that could shift profits to low-tax countries through patent activities [22]. Similarly, research by Mukherjee et al. (2017) analyzing changes in corporate tax rates at the state level in the United States found that increased tax rates significantly stifled corporate innovation activities [23], highlighting how higher corporate tax burdens could hinder firms from undertaking high-risk innovative investments. Additionally, studies by Zheng and Zhang (2018) analyzed how reductions in corporate income tax rates enhanced total factor productivity by optimizing resource allocation and easing financing constraints [5]. This finding aligns with research by Feng and Zong (2024) and Pelaez et al. (2024), who analyzed how capital tax incentives and total corporate tax burdens affect innovation investments, revealing the potential inhibitory effects of direct taxes on innovation investments [24,25]. In industry-specific analysis, research by Song and Wen (2023) explored the differing effects of fiscal subsidies and tax incentives in China's integrated circuit industry [26], finding that while subsidies might suppress technological innovation, tax incentives still played a promotional role in specific regions. This complements studies by Wang and Kesan (2022) [27], who examined how value-added tax policies facilitated corporate innovation activities by alleviating financing constraints, particularly in small and medium-sized enterprises. Further research by Wang et al. (2024), and Zhang and Song (2022) confirmed how tax policies create positive innovation incentives at both macro and micro levels [28,29].

In summary, these studies collectively underscore the significant role of tax policies in either encouraging or inhibiting corporate innovation, providing policymakers with insights into the complex factors to consider when designing tax policies. By understanding the dynamic relationship between tax policies and corporate innovation, policymakers can better formulate strategies to promote technological progress and economic growth, especially considering the diversity and depth across different regions, industries, and sizes of enterprises.

2.1.3. Determinants for corporate innovation

In exploring the determinants of corporate innovation, a comprehensive perspective encompasses several dimensions including financial support, corporate structure, internal dynamics, external collaborations, technological applications, and market environment, which together form a complex system that drives the innovative capabilities of firms.

Firstly, financial support is crucial for corporate innovation. Bernstein (2015) highlighted the dual impact of going public on a company's innovation activities [30]: although it increases financing capacity, it may also lead to a decline in innovation quality due to market myopia. Similarly, studies by Brown et al. (2009) [31] and Himmelberg and Petersen (1994) [32] showed that financial health, especially internal cash flows, is critical in supporting high-tech firms' innovation, emphasizing the direct impact of financial market conditions on innovative activities. Regarding corporate structure and cooperation mechanisms, Branstetter and Sakakibara (2002) found that research alliances significantly enhance the R&D output of participating companies, especially in a non-competitive environment where knowledge and resources are shared, thus strengthening firms' innovative capacities [33]. The internal drive and capabilities of a company are also significant catalysts for innovation. Research by Barrichello et al. (2020) indicated that while participation in R&D alliances does not necessarily enhance performance directly, product innovation in Colombian SMEs is crucial for enhancing competitive ability [34]. Moreover, Garcia-Montijo and Perez-Soltero (2018) highlighted the importance of links between academia and industry in fostering innovation by enhancing absorptive capacity, underlining the significance of cross-sector collaboration [35]. Technological applications also significantly impact corporate innovation. Li et al. (2020) analyzed how automation technologies have propelled the manufacturing sector from labor-intensive to technology-intensive, not only transforming the workforce structure but also promoting technological innovation and industrial upgrading [8]. Pan et al. (2022) further explored how the digital economy boosts sustainable development by enhancing total factor productivity [9]. Additionally, research by Qiao et al. (2021) examined the influence of pricing factors and social welfare on innovation efficiency, revealing differences between state-owned and private enterprises in fostering innovation efficiency [36]. Restrepo-Morales et al. (2019), along with Semensato et al. (2022), emphasized the complementarity between internal innovation and external collaboration, highlighting the roles of various factors in shaping an innovative ecosystem [37,38]. Finally, research by Wang et al. (2020) underscored the key role of the manufacturing sector in enhancing innovation efficiency in emerging economies, pointing out that the development of manufacturing is central to fostering innovation [39].

Overall, these studies indicate that corporate innovation results from a complex interplay of various factors, including financial support, adjustments in corporate structure, technological applications, and effective internal and external collaborations. Understanding these complex interactions is essential for developing effective corporate innovation strategies.

2.1.4. Literature synthesis

In discussing the impact of corporate income tax on technological innovation, although existing representative studies have provided important insights into the direct effects of tax rate changes on corporate innovation behavior [6,7], these studies still have limitations. They primarily focus on the direct effects of tax rate changes, seldom addressing how indirect pathways such as market competition influence innovation, and often neglect the geographical or spatial spillover effects of innovation, which may lead to biased estimates of tax impacts. Additionally, there is insufficient consideration of the heterogeneity in how tax rate changes affect firms of different productivity levels. Addressing these shortcomings, this paper proposes a comprehensive mathematical framework that not only explores the direct effects of tax rate changes but also systematically analyzes the indirect effects. For the first time, a spatial econometric model is used in empirical analysis to control for the geographical spillover effects of innovation, thus more accurately assessing the impact of corporate income tax reform on innovation. By categorizing firms according to productivity, this paper thoroughly investigates how tax rate changes affect firms of different productivity levels, enhancing understanding of the heterogeneity in tax policy impacts. These theoretical and methodological innovations not only fill the gaps in existing research but also provide robust theoretical and empirical support for designing more effective tax policies.

2.2. Theoretical model

This study builds on the endogenous innovation and firm heterogeneity competition model by Aghion et al. (2022), analyzing the impact of the corporate income tax rate on firm innovation [10]. This model explores how tax shocks produce asymmetric responses in corporate innovation activities and considers heterogeneity among firms, such that firms at different productivity levels respond variably to changes in the tax rate. By integrating existing economic theories and empirical data, this framework provides a comprehensive analytical tool for investigating the complex relationship between corporate income tax rate and corporate innovation.

The theoretical model consists of several core components: (1) The model sets up an optimization problem where firms maximize post-tax profits in a differentiated market. Firms adjust their output and innovation levels in response to market conditions and tax rate changes. (2) It introduces a representative consumer whose utility-maximizing behavior, coupled with the firms' cost functions, determines market prices and corporate production decisions. (3) The model analyzes firms' marginal benefits and costs to determine the optimal level of innovation and discusses how tax changes influence corporate innovation decisions by altering the degree of market competition. The detailed derivation process is included in Appendix A.

The analysis reveals that changes in the corporate income tax rate affect corporate innovation behavior through both direct and indirect effects. The direct effect manifests as changes in the costs and benefits of innovation due to tax adjustments, while the indirect effect influences innovation incentives through altered market competition dynamics. Additionally, the model predicts significant heterogeneity in the tax policy's impact on innovation across firms of varying productivity, with more productive firms exhibiting larger adjustments in their innovation levels in response to tax changes. Ultimately, the theoretical model posits three main propositions.

Proposition 1. *The reduction of corporate income tax rate enhances the competition level: a decrease in τ leads to an increase in λ, and vice versa.*

Proposition 2. *The overall effect on firms' innovation from a tax cut is ambiguous, depending on the relative magnitude of its direct effect versus the induced indirect competition effect. When the direct effect predominates, the innovation level increases.*

Proposition 3. *More productive firms with lower baseline costs will experience a greater increase in innovation levels.*

3. Empirical design

3.1. Data sources

This study leverages a robust dataset sourced from authoritative platforms to ensure reliability and depth in the analysis of corporate innovation influenced by tax changes. Primary data sources include Google Patent, which provides extensive global data on patent application citations (PAC) and patent grant citations (PGC), known for its comprehensive coverage and high credibility. Patent numbers obtained from the State Intellectual Property Office of China, the official national authority, facilitate the retrieval of relevant patents from Google Patent. Additional corporate data is sourced from the China Stock Market & Accounting Research Database (CSMAR) and Wind Information Co., Ltd. (Wind), which are the leading providers of data on listed companies in China, highly regarded for their accuracy and widely utilized in academic research. CSMAR provides control variables at the company level, while Wind offers detailed changes in corporate income tax rates. The National Bureau of Statistics of China supplies essential macroeconomic variables, adding a broader economic perspective to the study.

In aligning with rigorous data quality standards, our dataset was refined using criteria established by Zheng and Zhang (2018) and Wang (2014) [5,40]. Initially, any data pertaining to companies listed on the Science and Technology Innovation Board was excluded, along with any records missing crucial data points. Further exclusions applied to data from companies within the financial and insurance sectors, as well as companies reporting negative pre-tax profits or current income tax expenses. Additionally, observations where tax rates could not be determined, and data from high-risk (ST) companies, were also omitted. After these comprehensive data cleansing steps, over 24,000 observations from the years 2002–2020 were retained for analysis. The selection of the year 2002 as the starting point is strategic, marking the implementation of income tax-sharing reform in China, thereby minimizing potential distortions from concurrent tax policy changes. This approach ensures a robust dataset, enhancing the validity of the analysis on the impact of corporate income tax rates on innovation.

3.2. The definition of variables

Based on the established data sources and the cleaning process described, this section will construct the key variables for our analysis using the refined data set. We will develop these variables to rigorously test the study's hypotheses and ensure the empirical analysis is both precise and relevant.

3.2.1. Dependent variable

The dependent variable in our study is firm innovation, quantified by the number of patent citations as suggested by prominent research [6,7,41]. Unlike some studies that use the mere number of patents or R&D investment, patent citations provide a more robust indicator of innovation quality, reflecting substantive innovative output that is less susceptible to manipulation. We specifically utilize two forms of patent citations: Patent Application Citation (PAC) and Patent Granted Citation (PGC). Fig. 1 illustrates the density distribution of these two citation types, which exhibit high similarity, underscoring their reliability in assessing the impact of innovation.

3.2.2. Independent variable

The independent variable in this study is the changes in the corporate income tax rate. We utilize the CITR of 2008 in China as a proxy to address potential reverse causality and endogeneity concerns. This reform, the most extensive in China's history, primarily involved reducing the nominal corporate income tax rate from 33 % to 25 %. However, due to pre-reform complexities, the reform impacted firms differently: some retained a tax rate of 15 % (notably firms in Western Development Regions and high-tech companies), while others, particularly in special economic zones and foreign-funded enterprises, saw their rates gradually adjust to the 25 % nominal rate.

This diversity in tax changes allows us to categorize firms into three groups for analysis: those experiencing an increase in the nominal tax rate (Tax-up), those with a decrease (Tax-down), and those with unchanged rates (Tax-unchanged). We determine these groupings based on nominal rates from the CSMAR and Wind databases, supplemented by company annual reports and official websites for firms with missing data. A firm belongs to the Tax-down group if its post-reform tax rate is lower than its pre-reform rate, to the Tax-up group if the rate is higher, and to the Tax-unchanged group if there is no change.

Leveraging China's unique tax adjustments, we employ a Difference in Differences (DID) causal identification strategy. This method enables us to examine the varying impacts of tax rate changes on corporate innovation across the Tax-up and Tax-down groups within a unified analytical framework, testing the theoretical model's predictions. Fig. 2 illustrates the distribution of firms across these categories.

3.2.3. Control variables

The control variables in this study include firm size (Size), asset-liability ratio (Lev), proportion of independent directors (Board), property rights nature (Soe), profit margin (Profit), tangible assets proportion (Tangi), per capita capital (Capla), provincial economic development (Pergdp), and employment level (Employ), based on previous research [5,6,23,40]. All continuous variables are trimmed at the 1 % level to remove outliers. Detailed definitions and calculations for these variables are provided in Table 1.

3.3. Descriptive statistics

The descriptive statistics presented in Table 2 indicate that the means of PGC and PAC are closely aligned at 2.258 and 2.531,

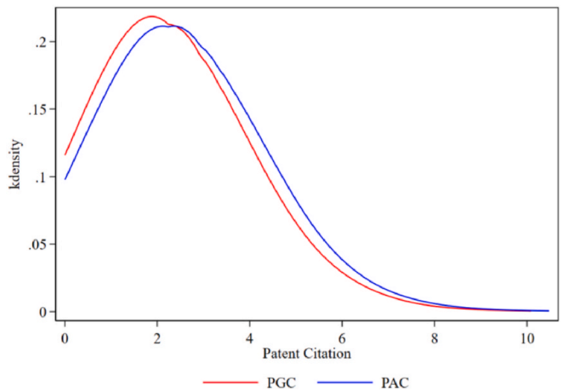

Fig. 1. Density distribution of patent citations.
Source: Author's estimation, using Stata software.

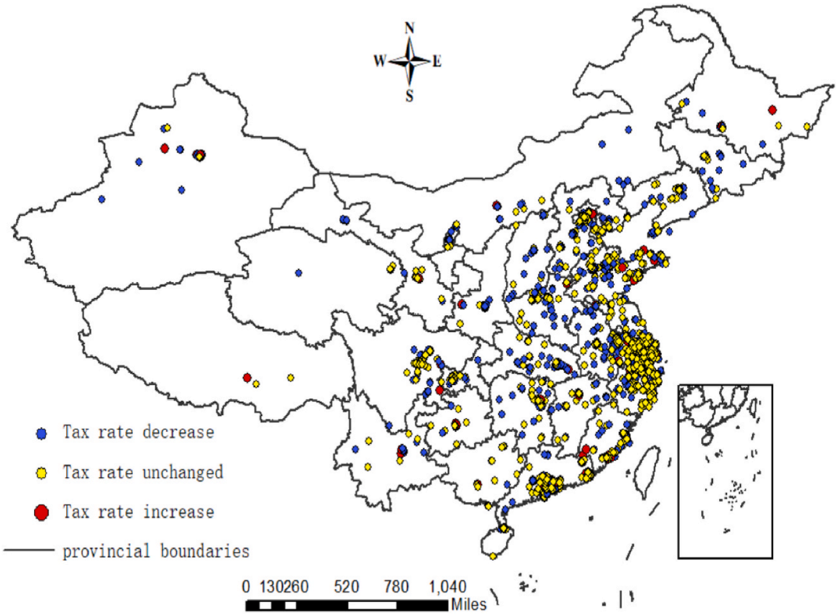

Fig. 2. Firm distribution of different groups.
Source: Author's estimation, using ArcGIS software.

respectively. For the tax groups post-reform, 6.9 % of the sample (average of Tax-up group) experienced an increase in tax rates, while 42.7 % (average of Tax-down group) enjoyed a decrease. Approximately 50 % of the sample maintained unchanged tax rates, aligning with findings from Zheng & Zhang (2018) [5]. Further descriptive statistics of other variables are available in the table without additional elaboration.

3.4. Econometric equation

To effectively identify the causal impact of CITR on innovation, we employ a DID model with two-way fixed effects, as advocated by Wang (2014) and Mukherjee et al. (2017) [23,40]. This model uses CITR as an exogenous shock to the corporate tax rate, thus addressing potential estimation biases due to endogeneity. The specific econometric equation is as follows:

$$\{PAC, PGC\}_{ipt} = \beta_0 + \beta_1 Post_{08}\#Tax\text{-}down_i + \beta_2 Post_{08}\#Tax\text{-}up_i + Z_{ipt} + \gamma_t + \delta_i + \mu_{ipt} \quad (1)$$

where PAC represents patent application citation, PGC represents patent granted citation, *i* indicates the firm, *p* the province, and *t* the year. $Post_{08}$ is a year dummy variable assigning a value of 1 to the years 2008 and onwards, and 0 otherwise. $Post_{08}\#Tax\text{-}down_i$ measures the effect of a reduction in the corporate tax burden on innovation for the Tax-down group following the CITR. Conversely, $Post_{08}\#Tax\text{-}up_i$ evaluates the impact of an increase in the corporate tax burden on innovation for the Tax-up group. Z_{ipt} includes a series of firm-level and provincial-level control variables. γ_t represents the year fixed effect, capturing influences of time-varying unobservable factors, while δ_i is the firm fixed effect, accounting for unobservable characteristics specific to the firm. μ_{ipt} denotes the error term. The coefficients $\beta 1$ and $\beta 2$ are of primary interest in this study, representing the total effects of corporate tax reductions and increases on corporate innovation, respectively. As outlined in Proposition 2 of the theoretical model, the direction of these coefficients is indeterminate and hinges on the relative magnitudes of the direct and indirect effects.

4. Results and discussion

4.1. Basic regression

Baseline results. In our baseline regression analysis, we rigorously evaluated the overarching impact of CITR on innovation, as detailed in Table 3. Initial results from columns (1)–(3), utilizing PAC as the dependent variable, reveal that the beneficial impact of a tax decrease (Tax-down#$Post_{08}$) on PAC, though somewhat diminished with the progressive inclusion of control variables and bidirectional fixed effects, remains statistically significant at the 1 % level. This suggests that the reduction in corporate tax rate notably enhances corporate innovation, evidenced by a 7.31 % increase in PAC. Conversely, the detrimental impact of a tax increase (Tax-up#$Post_{08}$) on PAC progressively intensifies and is also significant at the 1 % level, reflecting a substantial 9.08 % reduction in PAC due to the heightened corporate tax rate. Further analyses presented in columns (4)–(6), with PGC as the dependent variable, align with these findings. A decrease in the corporate income tax rate (Tax-down#$Post_{08}$) significantly boosts PGC by 8.89 %, whereas an increase

Table 1
Variable definitions and calculations.

Variable	Definition	Method of calculation
PGC	Patent granted citation	Log (1 + number of Patent license references), data mainly from Google Patent
PAG	Patent application citation	Log (1 + number of Patent application references), data mainly from Google Patent
Tax-up	Tax Increase Group	After the policy reform, the firms whose nominal income tax rate increases are assigned 1, and the rest are 0
Tax-down	Tax decrease Group	After the policy reform, the firms whose nominal income tax rate decreases are assigned 1, and the rest are 0
Size	Scale of firm	Log (1 + total firm assets (Yuan))
Lev	Asset-liability ratio	Total liabilities (Yuan)/total assets (Yuan)
Board	The proportion of independent directors	Number of independent directors/number of directors
Tangi	The proportion of tangible assets	(total assets-net intangible asset-net goodwill) total assets
Profit	Profit Margin	Profit before interest and tax (Yuan)/total assets (Yuan)
Soe	The nature of property rights	According to the nature of property rights, if it is a state-owned firm, the value is assigned to 1, and the others are 0
Capla	Capital per capita	Log (1 + tangible assets/business year-end number of people)
Pergdp	The economic development of the provinces	Log (1 + provincial GDP per capita (Yuan))
Employ	Level of employment in provinces	Log (1 + province population at year-end (10,000)

Source: Author’s estimation, using Stata software.

Table 2
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
PGC	25019	2.258	1.512	0	6.56
PAC	25019	2.531	1.564	0	6.957
Tax-up	25019	0.069	0.254	0	1
Tax-down	25019	0.427	0.495	0	1
Size	24382	22.224	1.317	19.918	26.364
Lev	24382	0.438	0.206	0.059	0.945
Board	24363	0.374	0.054	0.3	0.571
Tangi	24601	0.926	0.085	0.554	1
Profit	24545	0.053	0.07	−0.276	0.249
SOE	24321	0.389	0.487	0	1
Capla	24349	14.33	0.887	12.547	17.278
Pergdp	24293	11.069	0.531	9.404	12.013
Employ	24293	8.571	0.633	6.582	9.443

Source: Author's estimation, using Stata software.

Table 3
Basic regression results.

VARIABLES	PAC			PGC		
	(1)	(2)	(3)	(4)	(5)	(6)
Tax-down#Post$_{08}$	0.149***	0.100***	0.0731***	0.147***	0.114***	0.0889***
	(0.00297)	(0.00231)	(0.0164)	(0.00281)	(0.00220)	(0.0134)
Tax-up#Post$_{08}$	−0.0143**	−0.0617***	−0.0908***	−0.0116*	−0.0459***	−0.0691***
	(0.00627)	(0.00529)	(0.0178)	(0.00658)	(0.00536)	(0.0150)
Firm fixed	N	N	Y	N	N	Y
Year fixed	N	N	Y	N	N	Y
Controls	N	Y	Y	N	Y	Y
Observations	25,019	24,170	24,170	25,019	24,170	24,170
R-squared	0.314	0.554	0.660	0.365	0.468	0.671

Source: Author's estimation, using Stata software. Note: Robust standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

(Tax-up#Post$_{08}$) correspondingly depresses PGC by 6.91 %.

These baseline findings lead to two pivotal conclusions: First, the response of innovation to changes in corporate tax rate is symmetric—reductions and increases in corporate income tax rate exert opposing effects on innovation. This is because higher taxes reduce the available resources for firms to invest in research and development and other innovation activities. Conversely, lower taxes increase the funds available for these goals, thereby promoting innovation [23], which corresponds with the insights of Atanassov and Liu (2020) [6].

Dynamic test. A critical assumption underpinning the Difference-in-Differences (DID) methodology is the parallel trend hypothesis, which posits that the treatment and control groups must exhibit parallel trends in the absence of treatment for the results to be valid. To rigorously test this hypothesis and to explore the dynamic impacts of CITR, we employ an event study approach commonly

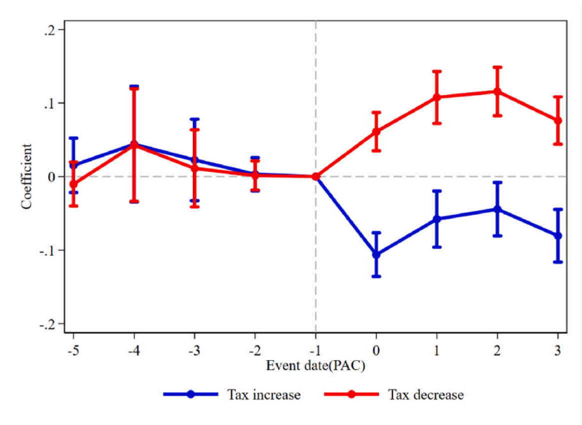

Fig. 3. The dynamic test of CITR
Source: Author's estimation, using Stata software.

used in finance. The specified econometric model is as follows:

$$\{PAC, PGC\}_{ipt} = \beta_0 + \sum_{T=-5}^{+4} \tau_{1,T} D_T \# Tax\text{-}down_i + \sum_{T=-5}^{+4} \tau_{2,T} D_T \# Tax\text{-}up_i + Z_{ipt} + \gamma_t + \delta_i + \mu_{ipt} \tag{2}$$

The model employs dummy variables D_T for the four intervals surrounding the 2008 tax reform. T = -1 serves as the baseline and is excluded from regression. Periods earlier than the fifth year pre-reform are grouped into T = -5, and those four years post-reform into T = +4. Parameters $\tau_{1,T}$ and $\tau_{2,T}$ measure the dynamic responses to tax decreases and increases, respectively. Regression outputs depicted in Figs. 3 and 4 verify that pre-reform tax-up and tax-down groups had no significant impact on innovation, maintaining the parallel trend requirement. Post-reform, CITR shows a significant effect on innovation, highlighting the reform's effectiveness in altering corporate innovation trajectories.

Placebo test. To address potential concerns regarding the random allocation of treatment and control groups, we conducted a placebo test. This test involved randomly assigning firms to treatment or control groups 200 times and analyzing the resulting treatment effects. By comparing these 200 simulated effects with the actual effect, we assessed the significance of differences. Figs. 5 and 6 display the distribution of these placebo effects for CITR's impact on PAC. The real coefficients (indicated by red lines) differ significantly from the placebo coefficients, confirming that the observed effects are attributable to the CITR and not to chance or unobserved variables influencing the outcomes. Similar results were observed for PGC, affirming the reform's significant impact on innovation. These details are omitted here due to space constraints.

4.2. Robust analysis

To verify the robustness of our primary regression outcomes, this section implements a series of rigorous robustness checks.

Truncated regression analysis. Given the distributional properties of PAC and PGC—both positive integers skewed right—an ordinary least squares regression may introduce bias. We thus apply a truncated regression model, revealing in Table 4 (columns 1–2) that decreases in corporate income tax rates enhance PAC and PGC growth rates by 8.44 % and 7.85 % respectively, while increases in corporate income tax rates decrease these rates by 7.34 % and 7.83 %. These findings reaffirm the stability of our basic regression results.

Self-Citation adjustment. To address the overestimation of innovation through self-citations—a practice potentially spurred by firms seeking to augment their perceived innovation for more favorable government incentives—we recalculated innovation metrics excluding self-citations. The adjusted results, detailed in Table 4 (columns 3–4), show a significant reduction in the corporate income tax rate on innovation, with growth rates not exceeding 6 %. Despite this adjustment, the results robustly support our initial conclusions.

Addressing self-selection bias. Potential self-selection by firms, through strategic relocations or industry reclassification to benefit from favorable tax conditions, could compromise the randomness of treatment versus control groups. We employed a Propensity Score Matching (PSM) approach to correct for such biases by excluding firms likely to engage in such behaviors and recalibrating the control and treatment groups. As shown in Table 4 (columns 5–6), this adjustment amplifies the effects of CITR on innovation, with both promotional and inhibitory impacts on innovation growth rates exceeding 10 %, indicating that the basic regression may have underestimated these effects due to corporate strategic behaviors.

4.3. Mechanism analysis

This section is dedicated to examining both the direct and indirect effects of CITR on innovation, serving two main objectives:

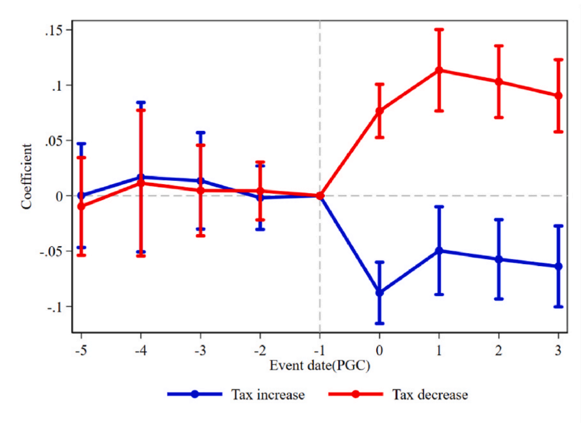

Fig. 4. The dynamic testing of CITR
Source: Author's estimation, using Stata software.

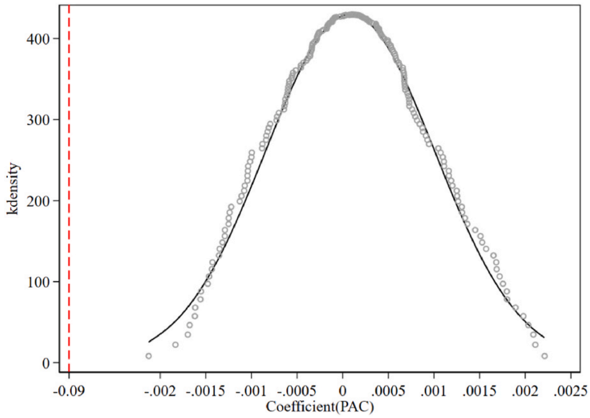

Fig. 5. Placebo test of tax increase.
Source: Author's estimation, using Stata software.

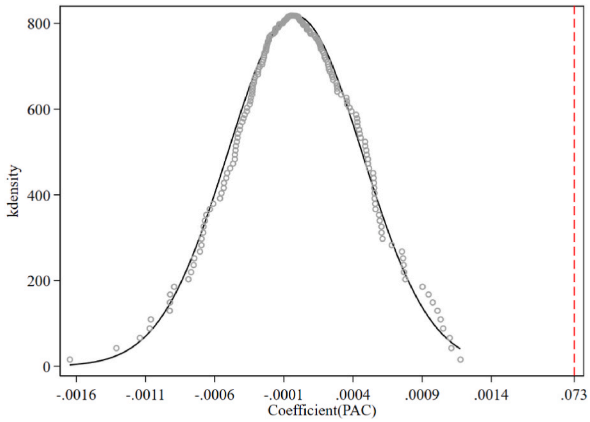

Fig. 6. Placebo test of tax decrease.
Source: Author's estimation, using Stata software.

Table 4
Robust results.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	PAC	PGC	PAC	PGC	PAC	PGC
Tax-down#Post$_{08}$	0.0844***	0.0785***	0.0561***	0.0558**	0.111***	0.109***
	(0.00109)	(0.00103)	(0.0155)	(0.0235)	(0.00157)	(0.00149)
Tax-up#Post$_{08}$	−0.0734***	−0.0783***	−0.0349**	−0.0538**	−0.120***	−0.119***
	(0.00184)	(0.00175)	(0.0163)	(0.0252)	(0.00312)	(0.00291)
Firm fixed	Y	Y	Y	Y	N	Y
Year fixed	Y	Y	Y	Y	N	N
Controls	Y	Y	Y	Y	Y	N
Observations	24,170	24,170	24,170	24,170	24,170	24,170
R-squared	N	N	0.696	0.628	N	N

Source: Author's estimation, using Stata software. Note: Robust standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

Firstly, to verify the accuracy of the theoretical model's decompositions and predictions; and secondly, to validate the fidelity of the basic regression outcomes. We employ the causal steps framework developed by Baron & Kenny (1986) to rigorously assess these effects [42]. The corresponding econometric model is structured as follows:

$$Competition_{dt} = \beta_0 + \beta_3 Post_{08}\#Tax\_down_i + \beta_4 Post_{08}\#Tax\_up_i + Z_{ipt} + \gamma_t + \delta_i + \mu_{ipt} \quad (3)$$

$$\{PAC, PGC\}_{ipt} = \beta_0 + \beta_5 Post_{08}\#Tax\_down_i + \beta_6 Post_{08}\#Tax\_up_i + \beta_7 Competition_{dt} + Z_{ipt} + \gamma_t + \delta_i + \mu_{ipt} \quad (4)$$

Where $Competition_{dt}$ means the degree of market competition in equations (3) and (4), measured by the Herfindahl Index (HHI) of the main business income of firms in the industry. The higher the HHI, the less competitive the market is, so "1-HHI" treatment is adopted to facilitate the interpretation of the results. d is for industry, and other variables are the same as before. According to the theoretical model, the interaction term $\beta_3 \times \beta_7$ and $\beta_4 \times \beta_7$ measure the indirect effects of the rise and reduction of the corporate income tax rate on innovation, with the signs expected to be negative and positive respectively according to Proposition 1. And β_5 and β_6 state the direct effects of the rise and reduction of corporate income tax rate on innovation are measured, with signs expected to be positive and negative, respectively. All the other coefficients β_3, β_4, β_7 are expected to be negative.

Table 5 presents the detailed regression outcomes: Column (1) demonstrates that a reduction in the corporate income tax rate significantly promotes market competition (coefficient = 0.0867), while an increase in the corporate income tax rate significantly decreases it (coefficient = −0.0482), supporting Proposition 1. Column (2) reveals that a decline in the corporate income tax rate significantly enhances PAC directly (coefficient = 0.0745), whereas an increase in tax rate directly reduces PAC (coefficient = −0.0914). Concurrently, market competition exerts a notable inhibitory influence on PAC, consistent with theoretical expectations. The calculated indirect effect of a reduction in the corporate income tax rate on PAC through market competition is −0.00120 (−0.0138 * 0.0867), and the indirect effect of an increase in the corporate income tax rate on PAC through market competition is 0.00441 (−0.0482 * −0.0914). These indirect effects are less pronounced than the direct effects, confirming that the overall effect follows the direction of the direct impact. Column (3) illustrates that the reduction of the corporate income tax rate significantly boosts PGC (coefficient = 0.0896), whereas increasing in corporate income tax rate directly hinders PGC (coefficient = −0.0694). Similarly, market competition exerts a substantial negative effect on PGC, in line with theoretical expectations. The indirect effect of tax reduction on PGC through market competition is −0.000501 (−0.00578 * 0.0867), and the indirect effect of tax increase on PGC through market competition is 0.000279 (−0.0482 * −0.00578). Again, these indirect effects are smaller than the direct effects, supporting that the total effect aligns with the direct impact.

The findings suggest that the direct impact of corporate tax rate adjustments on innovation predominates over any indirect effects. Consequently, both the direction and magnitude of the total and direct effects are aligned, supporting the notion posited by Stantcheva (2021) that the influence of tax policies on innovation remains a subject for empirical investigation [43]. The findings also align with existing literature that suggests the complexity of tax policy impacts innovation. For instance, research has shown that lower corporate tax rates can significantly boost investment and entrepreneurship by reducing the cost burden on businesses [44]; Mukherjee et al. (2017) demonstrate that increased state-level corporate taxes in the United States lead to reduced future innovation [23]. Similarly, He et al. (2023) observe that China's super deduction for R&D expenditures positively influences innovation [45].

Additionally, this study extends our understanding of the mechanisms through which tax changes affect innovation. Market competition introduces an indirect pathway through which tax rates affect innovation. In a competitive market, firms are compelled to innovate to maintain or enhance their market position [46]. However, the relationship between tax rates and market competition can produce counterintuitive effects. Higher taxes might lead to reduced competition because smaller or less efficient firms cannot survive the increased financial burden, thereby reducing overall market competition, which might diminish the pressure on surviving firms to innovate, as their competitive threats are reduced [47]. On the other hand, lower taxes could enhance competition by allowing more firms to thrive, thus increasing the competitive pressure to innovate. This finding aligns with previous research that emphasizes tax cuts significantly enhance innovation, especially for firms operating in a more competitive and favorable business environment [6].

4.4. Heterogeneity analysis

This section evaluates Proposition 3, which hypothesizes productivity heterogeneity in the effects of CITR on innovation. Specifically, it posits that the impact of CITR on innovation is more pronounced in high-productivity firms than in low-productivity ones. Productivity is measured using both the Olley-Pakes (OP) and Levinsohn-Petrin (LP) methods. Fig. 7 illustrates the distribution of Total Factor Productivity (TFP) calculated by these methods, underscoring the differential impacts across productivity levels.

We conducted a median grouping regression analysis to explore productivity heterogeneity's effect on the impact of CITR on

Table 5
Mechanism results.

VARIABLES	(1)	(2)	(3)
	Competition	PAC	PGC
Tax-down#Post$_{08}$	0.0867***	0.0745***	0.0896***
	(0.0143)	(0.0163)	(0.0133)
Tax-up#Post$_{08}$	−0.0482**	−0.0914***	−0.0694***
	(0.0190)	(0.0177)	(0.0149)
Competition		−0.0138***	−0.00578*
		(0.00405)	(0.00314)
Firm fixed	Y	Y	Y
Year fixed	Y	Y	Y
Controls	Y	Y	Y
Observations	24,115	24,115	24,115
R-squared	0.049	0.662	0.672

Source: Author's estimation, using Stata software. Note: Robust standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

innovation, employing two additional methods to ensure robustness: Fisher's Permutation Test for significance between groups and Chow's Test for differences between regression lines. The results, displayed in Table 6, reveal that both the promotion of innovation by tax reduction (*Tax-down#Post08*) and the inhibition by tax increase (*Tax-up#Post08*) are more pronounced in the high TFP group. Fisher's Permutation Test confirms significant differences in the regression coefficients across groups. Chow's Test, further applying a product interaction between CITR and a binary TFP variable (1 for high TFP firms; 0 otherwise), shows that both the positive impact of *Tax-down#Post08#OP* and the negative impact of *Tax-up#Post08#OP* on innovation amplify with higher TFP, aligning with our hypotheses. Columns (4)–(5) extend this analysis to PGC, with consistent results affirmed by Chow's Test in Column (6), reinforcing the robustness of our findings.

The results confirm that higher tax rates discourage innovation, especially in high-productivity firms, underscoring the detrimental effects of increased tax burdens on innovation capacity. As high-productivity firms typically have better access to resources and can reallocate them more efficiently in response to tax changes, being more capable of leveraging additional resources resulting from tax reductions to enhance their innovative capabilities [48]. Moreover, high-productivity firms usually benefit from economies of scale, which magnify the effects of tax rate changes. Lower taxes can lead to significant cost savings, which can be reinvested into the business, thus boosting innovation and productivity [49].

4.5. Spatial analysis

As widely recognized, innovation tends to exhibit positive spillover effects, raising concerns about potential free-riding by neighboring firms. This aspect has been underexplored in existing literature, particularly regarding how the corporate income tax rate might influence innovation when accounting for such spatial dependencies. Previous studies, notably by Mukherjee et al. (2017), have touched upon spatial aspects using policy discontinuities at borders between similar states but concluded that economic conditions did not drive their findings [23]. Building on this groundwork, this section introduces a rigorous application of spatial econometric models to control for neighbor spillover effects, aiming for more precise causal inference.

It is crucial to note that China's 2008 CITR was not implemented at the administrative regional level, making traditional difference-in-differences (DID) approaches inapplicable for spatial analyses. Therefore, we aggregate firm-level data to the provincial level, employing the average nominal income tax rate and the number of patent citations per province as core variables. Other controls remain unchanged. Prior to implementing spatial regression, we assess the presence of spatial autocorrelation in provincial innovation via the Moran Index, a standard measure in spatial analysis. The Moran Index's plot, detailed in Appendix B, indicates significant spatial spillover effects, validating the necessity of our spatial regression approach.

We conducted regression analyses using three classic spatial models: the Spatial Autoregression Model (SAR), Spatial Durbin Model (SDM), and Spatial Error Model (SEM), with detailed equations provided in Appendix C. The empirical results presented in Table 7 illustrate the effects of the corporate income tax rate on innovation. In SAR (Columns 1–2), each percentage point increase in corporate income tax rate leads to a reduction in the growth rates of PAC and PGC by 9.74 % and 9.5 %, respectively. Furthermore, innovation in neighboring provinces significantly boosts local innovation, increasing the growth rate by 0.87 % and 1.12 % for PAC and PGC, respectively, indicating a robust positive spillover effect (λ is significantly positive). These results affirm that even after controlling for the innovation effects from neighboring provinces, a rise in corporate income tax rate substantially depresses local innovation levels.

The SDM results (Columns 3–4) reinforce these findings, showing that each unit increase in the corporate tax rate depresses PAC and PGC growth rates by 9.7 % and 8.89 %, respectively. Simultaneously, tax changes in neighboring provinces exert a substantial positive influence (δ is significantly positive), enhancing the local innovation growth rate by 22.7 % and 42.4 %, respectively. This demonstrates that, notwithstanding the positive regional tax influences, local innovation declines with an increase in the corporate income tax rate.

Lastly, the SEM results (Columns 5–6) indicate that each unit rise in corporate income tax rate reduces PAC and PGC growth rates

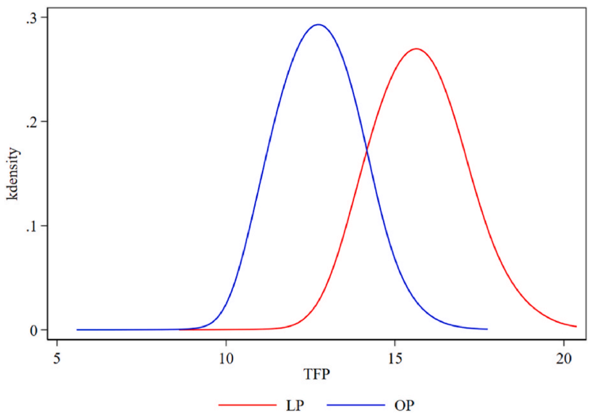

Fig. 7. The distribution of TFP
Source: Author's estimation, using Stata software.

Table 6
Heterogeneity analysis.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	High TFP	Low TFP	Chow	High TFP	Low TFP	Chow
	PAC	PAC	PAC	PGC	PGC	PGC
Tax-down#Post$_{08}$	0.145**	0.0692***		0.456***	0.0847***	
	(0.0621)	(0.0138)		(0.0597)	(0.0116)	
Tax-up#Post$_{08}$	−0.167***	−0.0771***		−0.109***	−0.0686***	
	(0.0130)	(0.0150)		(0.0117)	(0.0143)	
Tax-down#Post$_{08}$#OP			0.00221***			0.00221***
			(0.000550)			(0.000550)
Tax-up#Post$_{08}$#OP			−0.00978***			−0.00978***
			(0.00128)			(0.00128)
Fisher's Permutation	0.000***			0.000***		
Firm fixed	Y	Y	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y
Observations	12,076	12,094	24,161	12,076	12,094	24,161
R-squared	0.651	0.629	0.643	0.673	0.640	0.643

* * *p < 0.01, * *p < 0.05, *p < 0.1.
Source: Author's estimation, using Stata software. Note: Robust standard errors in parentheses,

Table 7
Spatial regression.

VARIABLES	SAR		SDM		SEM	
	PAC	PGC	PAC	PGC	PAC	PGC
	(1)	(2)	(3)	(4)	(5)	(6)
Tax	−0.0974**	−0.0950**	−0.0970*	−0.0889*	−0.0993**	−0.106**
	(0.0425)	(0.0406)	(0.0483)	(0.0475)	(0.0462)	(0.0445)
λ	0.00870**	0.0112***				
	(0.00420)	(0.00285)				
δ			0.227**	0.424***		
			(0.108)	(0.0854)		
ρ					0.000334	0.00483
					(0.00436)	(0.00467)
Firm fixed	Y	Y	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y
Observations	431	431	431	431	431	431
R-squared	0.962	0.952	0.961	0.952	0.960	0.948

* * *p < 0.01, * *p < 0.05, *p < 0.1.
Source: Author's estimation, using Stata software. Note: Robust standard errors in parentheses,

by 9.93 % and 10.6 %, respectively. The non-observable errors from neighboring provinces show no significant impact on local innovation (ρ is not significant), which aligns with the consistency observed in earlier findings, substantiating the robustness of the basic regression results under various spatial considerations.

5. Conclusions and implications

5.1. *Main findings*

In the light of the popularity of tax income tax changes and innovation outcomes and the scant research on market competition mechanisms in complex business contexts, this study set out to explore the impact of corporate income tax rates on innovation from both theoretical and empirical perspectives. The findings demonstrate that increasing the corporate income tax rate significantly hinders corporate innovation, whereas decreasing significantly boosts it, highlighting a symmetrical effect. These findings are substantiated through a series of robustness checks. Moreover, further mechanism tests indicate that the direct effects of corporate income tax rates on innovation outweigh its indirect effects through market competition, underpinning the outcomes of the basic regression. Furthermore, heterogeneity tests reveal that the impact of changes in corporate income tax rates is more pronounced in high-productivity firms. Further spatial analyses, considering the spillover effects of innovation, affirm the validity of the conclusions.

5.2. Theoretical contributions

This research introduces two marginal innovations: Firstly, the development and validation of a novel theoretical model that encapsulates both direct and indirect mechanisms of impact, filling a significant gap in the literature by elucidating the multilayered mechanisms through which tax rate changes affect corporate innovation. Secondly, it pioneers the use of spatial econometric models in examining the relationship between tax rates and corporate innovation, particularly emphasizing the control of geographical or regional spillover effects. This methodological advancement not only enhances the accuracy of assessing tax rate impacts but also provides a nuanced understanding of the dynamic interplay between tax policy and corporate innovation.

5.3. Practical implications

The results of this study have several practical implications for policymakers and business managers.

First, reducing corporate income tax rates, especially for high-productivity firms, can significantly promote innovation. Policymakers can implement tax incentives and lower tax rates to create a more conducive environment for R&D and innovation activities. While tax reductions can promote innovation, they must be balanced against potential reductions in government revenue. This requires careful consideration to ensure that essential public spending on education, infrastructure, and R&D is not compromised.

Second, regulating competition to a certain level is important. Excessive competition can undermine the benefits of tax reductions on innovation. Regulatory bodies should monitor market dynamics to prevent anti-competitive practices and ensure that competition remains healthy and conducive to innovation. Regulatory structures can be enhanced to maintain an optimal level of competition that encourages firms to innovate without overwhelming them.

Third, enhancing patent protection for firms is vital due to the significant positive spillovers associated with corporate innovation. Protecting independent R&D efforts and imposing stricter penalties on firms that engage in free-riding behaviors are essential measures to safeguard the interests of innovation-driven firms. This approach ensures that firms are properly incentivized to invest in innovation, benefiting the broader economy through technological advancements and competitive growth.

By designing tax policies that integrate various aspects of economic growth, such as innovation and market competition, governments and businesses can create a more innovation-friendly environment that drives economic growth and competitiveness.

5.4. Limitations and future research

This study has identified certain limitations, indicating possible directions for future research. Firstly, this article does not consider the threshold effects of market competition mechanisms, specifically whether the indirect effects of increasing market competition might exceed the direct effects within certain intervals, potentially altering the fundamental conclusions of this study. Addressing this could significantly enhance our understanding of the mechanisms at play and assist in developing more effective policies. Moreover, the theoretical model presented here does not adequately account for the phenomenon observed in Nordic countries, where high tax rates are associated with high levels of innovation. These limitations highlight important areas for future research.

Funding statement

This work was supported by the Fundamental Research Funds for the Provincial Universities of Zhejiang (Number: 2024ZD25).

Data availability statement

The data that support the findings of this study are available from the corresponding author.

CRediT authorship contribution statement

Bin Sang: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Huzhou Zhu:** Writing – review & editing, Visualization, Methodology. **Chunyuan Zhang:** Investigation, Formal analysis, Data curation. **Wenqiang Yin:** Resources, Investigation, Formal analysis. **Lin Guo:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

We start by analyzing how exogenous tax shock induces a skewed innovation response from Aghion et al. (2022)'s model of endogenous innovation and competition with firm heterogeneity. There are two key propositions in the model. The first is that tax cut will intensify the market competition and change the demand conditions faced by firms, weakening their incentives to innovate. The second is that more productive firms will respond to this tax shock with a larger increase in their level of innovation.

Optimization and innovation choice

There is one differentiated sector in which each firm sells its variety. A representative consumer has preferences over the continuum of differentiated varieties indexed by $i \in [0, M]$, who chooses the quantities q_i to optimize her aggregate utility facing prices p_i:

$$max_{q_i \geq 0} \int_0^M u(q_i)dx \ \ s.t. \int_0^M p_i q_i di = 1. \tag{1}$$

We assume that the representative consumer has additively separable preferences with sub-utility:

$$u(q_i) = \alpha q_i - \frac{\beta q_i^2}{2}. \tag{2}$$

Where $\alpha > 0$ and $\beta > 0$. Combine equation (1) and equation (2), the inverse demand function is given by $p(q_i; \lambda) = \frac{u'(q_i)}{\lambda} = \frac{\alpha - \beta q_i}{\lambda}$. The larger the Lagrange multiplier $\lambda = \int_0^M u'(q_i) q_i di$, the lower price per variety, which means a more significant competition effect.

Given the monopolistic competitive setting, by innovating k, a firm can reduce its baseline marginal cost of production c, which represents its productivity level by εk. And the cost of innovation is quadratic in k, equal to $\gamma_1 k + \frac{\gamma_2}{2} k^2$. A firm c will choose the output per consumer q_i, and innovation level k to maximize its after-tax profit[1, 2 and 3]:

$$max_{q(c;\lambda), k(c;\lambda)} \Pi(c, k; \lambda) = (1 - \tau)\{[p(q_i; \lambda) - (c - \varepsilon k)] q_i L - f\} - \gamma_1 k - \frac{\gamma_2}{2} k^2. \tag{3}$$

Where τ is the CITR, L is the exogenous level of market size, f is the fixed production cost. Given the optimal output $q(k; \lambda) = \frac{\alpha - (c - \varepsilon k)\lambda}{2\beta}$, the firm will choose its optimal innovation level $k(c; \lambda)$ to further maximize:

$$\Pi(c, k; \lambda) = (1 - \tau)\left\{\frac{[\alpha - (c - \varepsilon k)\lambda]^2}{4\beta\lambda} L - f\right\} - \gamma_1 k - \frac{\gamma_2}{2} k^2. \tag{4}$$

Equation (4) tells us that the marginal benefit (MB) and the marginal cost (MC) of innovation are given respectively by equation (5) and equation (6):

$$MB(c, k) = (1 - \tau)\frac{\varepsilon L(\alpha - c\lambda)}{2\beta} + (1 - \tau)\frac{\varepsilon^2 L\lambda}{2\beta} k, \tag{5}$$

$$MC(c, k) = \gamma_1 + \gamma_2 k. \tag{6}$$

There exists an optimal $k^*(c; \lambda) > 0$ to satisfy $MB(c; k) = MC(c; k)$[2]:

$$k^*(c; \lambda) = \frac{(1 - \tau)\varepsilon L(\alpha - c\lambda) - 2\beta\gamma_1}{2\beta\gamma_2 - (1 - \tau)\varepsilon^2 L\lambda}. \tag{7}$$

Note that only firms with c below the cutoff value $\widehat{c}_i = \frac{1}{\lambda}\left[\alpha - \frac{2\beta\gamma_1}{(1-\tau)\varepsilon L}\right]$ which satisfies $k^*(\widehat{c}_i; \lambda) = 0$ will find it profit to innovate, otherwise won't choose to do that.

Zero cutoff profit and free entry

In this subsection, we will describe how the zero cutoff profit (ZCP) condition and free entry (FE) condition endogenously determine the competition level λ.

We assume that firms' baseline marginal cost c follows the distribution $G(c)$ with support on $[c_{min}, +\infty)$. ZCP condition requires that it's profitable to produce only for firms with c below a cutoff value $\widehat{c}_e$ that satisfies $\Pi(\widehat{c}_e, 0; \lambda) = 0$. From equation (4), we have:

$$\frac{(\alpha - \widehat{c}_e \lambda)^2}{4\beta\lambda} L = f. \tag{8}$$

Combing firms' innovative strategies, it can be concluded that firms with $c \in [\widehat{c}_e, +\infty)$ will exit, firms with $c \in [\widehat{c}_i, \widehat{c}_e)$ will produce

[1] R&D spending is excluded from the tax scope in this study.

[2] Referring to Aghion et al. (2022),we make two assumptions in the model. First, we assume that $c > c_{min} \equiv \varepsilon k(c_{min}; \lambda) = \frac{\varepsilon}{\gamma_2}\left[\frac{(1-\tau)\alpha\varepsilon L}{2\beta} - \gamma_1\right]$ to ensure that even the ex-post marginal cost of the most productive firms is still larger than zero after innovating. Second, we assume that $\gamma_2 > (1 - \tau)\frac{\varepsilon^2 L\lambda}{2\beta}$ and $\gamma_1 < (1 - \tau)\frac{\varepsilon L(\alpha - c\lambda)}{2\beta}$ to ensure the existence of unique optimal innovation level $k^*(c; \lambda) > 0$.

but not innovate, and firms with $c \in (c_{min}, \widehat{c}_i)$ will produce and innovate.

Besides, FE condition requires that the expected after-tax profit conditional on successful entry must equal the fixed sunk entry cost f_e. From equation (4), we have:

$$\int_{c_{min}}^{\hat{c}_e} (1-\tau)\left\{\frac{[\alpha-(c-\varepsilon k)\lambda]^2}{4\beta\lambda}L - f\right\} - \gamma_1 k - \frac{\gamma_2}{2}k^2 dG(c) = f_e. \tag{9}$$

It can be proved that there exists a unique pair $(\lambda, \widehat{c}_e)$ jointly determined by ZCP condition (see equation (8)) and FE condition (see equation (9)),[3] and we also have:

Proposition 1. *The reduction of CITR enhances the competition level: a decrease in τ leads to an increase in λ and vice versa.*

The heterogeneous innovation response to tax cut

In this subsection, we take the example of tax cut to analyze how firms' optimal innovation decisions with $c \in (c_{min}, \widehat{c}_i)$ response to potential CITR shocks. More details will be discussed theoretically and graphically (see Fig. 1).

Consider firm c_l and firm c_h with different baseline marginal cost. Note that $\frac{dk^*(c;\lambda)}{dc} < 0$ from equation (7), thus the optimal innovation level is higher for more productive firms. As we can see from Fig. 1, $k_l^* > k_h^*$. We then explore a tax cut's direct and indirect effects from the induced increase in the competition level. Finally, the direction of the overall effect will also be discussed.

Direct effect. Holding the competition level λ fixed, tax cut has a direct positive effect on firms' optimal innovation level because of

$$\frac{\partial k^*(c;\tau,\lambda)}{\partial \tau} = \frac{2\beta\varepsilon\lambda[\gamma_1\varepsilon\lambda - (\alpha - c\lambda)\gamma_2]}{[2\beta\gamma_2 - (1-\tau)\varepsilon^2 L\lambda]^2} < 0. \tag{10}$$

Fig. 1 shows that if the tax rate falls, both the intercept and slope of MB curve increase ($MB(k) \rightarrow MB'(k)$), but MC curve keeps unchanged, leading to an increase in firms' innovation ($k^* \rightarrow (k^*)'$), consistent with equation (10).

However, this direct innovation response to tax cut is larger for more productive firms with lower c because of

$$\frac{\partial\left|\frac{\partial k^*(c;\tau,\lambda)}{\partial \tau}\right|}{\partial c} < 0. \tag{11}$$

Fig. 1 shows that although the increase in the slope keeps the same, the tax cut induces a larger increase in the intercept of the MB curve of the firm c_l with low baseline marginal cost ($MB_l(k) \rightarrow MB_l'(k)$), but a smaller increase in that MB curve of the firm c_h with high baseline marginal cost ($MB_h(k) \rightarrow MB_h'(k)$), thus making a bigger rise in firm c_l's innovation level ($k_l^* \rightarrow (k_l^*)'$) than firm c_h's ($k_h^* \rightarrow (k_h^*)'$), consistent with equation (11).

Indirect effect. The competition level λ will change with the CITR. Note that $c > c_{min}$ ensures that

$$\frac{\partial k^*(c;\tau,\lambda)}{\partial \lambda} = \frac{\varepsilon\lambda[(1-\tau)\alpha\varepsilon^2 L - 2\beta(\gamma_1\varepsilon + \gamma_2 c)]}{[2\beta\gamma_2 - (1-\tau)\varepsilon^2 L\lambda]^2} < 0. \tag{12}$$

Proposition 1 and equation (12) tell us that the tax cut leads to a higher competition level, which makes firms respond by reducing innovation ($(k^*)' \rightarrow (k^*)''$). Fig. 1 shows that owing to the competition effect, the intercept of the MB curve further decreases even though its slope increases a little bit ($MB'(k) \rightarrow MB''(k)$). Besides, we also find that the competition effect also induces a larger reduction in innovation for those less productive firms with higher c because of the negative relationship between the change in c and λ, as shown in equation (13).

$$\frac{\partial\left|\frac{\partial k^*(c;\tau,\lambda)}{\partial \lambda}\right|}{\partial c} < 0. \tag{13}$$

As we can see from Fig. 1, although the increase in the slope remains the same, the competition effect induces a more significant reduction in the intercept of the MB curve of firm c_h ($MB_h'(k) \rightarrow MB_h''(k)$), but a smaller reduction in that of firm c_l ($MB_l'(k) \rightarrow MB_l''(k)$), leading to a larger fall in the innovation level for firm c_h ($(k_h^*)' \rightarrow (k_h^*)''$) than firm c_l ($(k_l^*)' \rightarrow (k_l^*)''$).

Overall effect. It can be learned from the analysis above that the tax cut has a positive direct effect on firms' optimal innovation level. However, the induced competition effect, as shown in in equation (14), has a negative indirect effect on that, which breaks down the total effect of tax cut on innovation.

[3] The existence and uniqueness of pair $(\lambda, \widehat{c}_e)$ can be proved referring to Aghion et al. (2022).

$$\underbrace{\frac{dk^*(c;\tau,\lambda)}{d\tau}}_{\text{overall effect}} = \underbrace{\overbrace{\frac{\partial k^*(c;\tau,\lambda)}{\partial \tau}}^{<0}}_{\text{direct effect}} + \underbrace{\overbrace{\frac{\partial k^*(c;\tau,\lambda)}{\partial \lambda}}^{<0}\overbrace{\frac{\partial \lambda}{\partial \tau}}^{<0}}_{\text{indirect effect}}. \tag{14}$$

Fig. 1 shows that if the positive direct effect overcomes the negative indirect effect, the overall effect would still be positive, thus increasing firms' innovation level ($k^* \rightarrow (k^*)''$).

Proposition 2. *The overall effect on firms' innovation of tax cut is ambiguous depending on the relative size of its direct effect and the induced indirect opposite competition effect. When the former one is larger, the innovation level will increase.*

We can also divide the overall heterogeneous effect into the direct part, and the indirect part, the direction of which is deterministic:

$$\underbrace{\frac{d\left|\frac{\partial k^*(c;\tau,\lambda)}{\partial \tau}\right|}{dc}}_{\text{overall heterogeneous effect}} = \underbrace{\overbrace{\frac{\partial\left|\frac{\partial k^*(c;\tau,\lambda)}{\partial \tau}\right|}{\partial c}}^{<0}}_{\text{direct heterogeneous effect}} + \underbrace{\overbrace{\frac{\partial\left|\frac{\partial k^*(c;\tau,\lambda)}{\partial \lambda}\right|}{\partial c}}^{>0}\overbrace{\frac{\partial \lambda}{\partial \tau}}^{<0}}_{\text{indirect heterogenous effect}} < 0. \tag{15}$$

Consistent with equation (15), Fig. 1 shows that the tax cut yields a larger positive direct effect and a smaller negative indirect effect on firm c_l than firm c_h, thus increase in the innovation level is more pronounced for the former one ($k_l^* \rightarrow (k_l^*)''$; $k_h^* \rightarrow (k_h^*)''$).

Proposition 3. *The more productive firm with lower baseline cost will increase the innovation level more.*

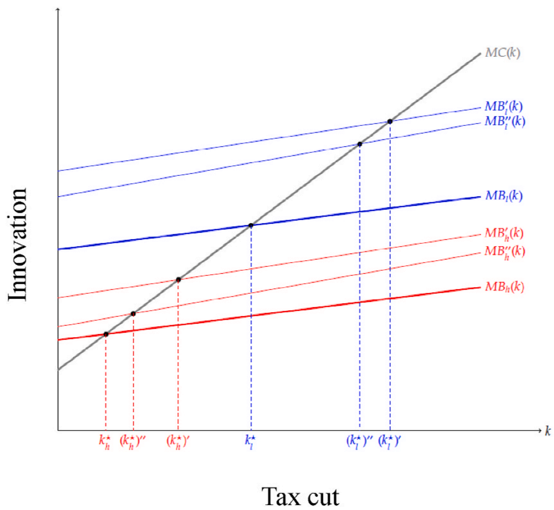

Fig. 1. A skewed Innovation Response to Tax Cut.
Source: Author's estimation, using Stata software.

To sum up, despite the uncertainty about the impact of tax cut on firms' innovation, firms will respond with a higher innovation incentive on average if the magnitude of the shock's direct effect is larger than the induced indirect competition effect. Besides, the increase in the level of innovation is more pronounced for more productive firms.

Appendix B

The Moran Index is measured by the following formula:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(x_i\text{-}\bar{x})(x_j\text{-}\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}} \tag{16}$$

where $S^2 = \frac{\sum_{i=1}^{n}(x_i\text{-}\bar{x})^2}{n}$ means the sample variance of the innovation level x_i for region i, ω_{ij} states the (i,j) element of the spatial weight matrix, $\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}$ is the sum of all spatial weights. Figs. 2 and 3 visually show the degree of spatial autocorrelation of innovation, and we can judge that there is significant spatial autocorrelation in innovation, which accords with our intuition.

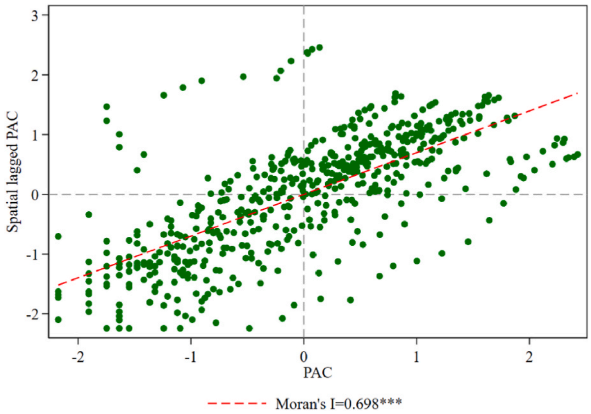

Fig. 2. Moran Scatterplot (PAC).
Source: Author's estimation, using Stata software.

Note: PAC is standardized; spatial lagged PAC is a Spatial lag term of PAC, which is also standardized according to the calculation of the adjacent Spatial weight matrix. Moran's I is the slope of linear fitting between PAC and Spatial lagged PAC, which is significant at 1 % level.

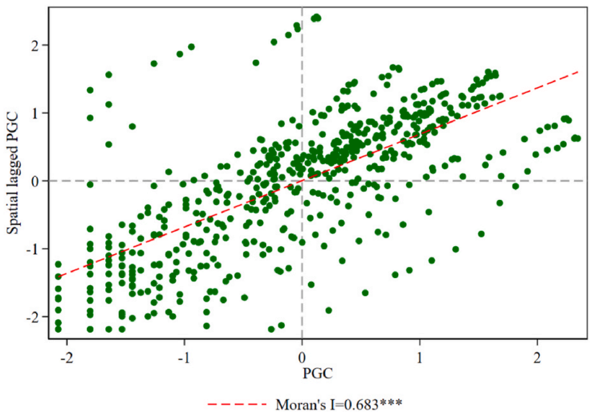

Fig. 3. Moran Scatterplot (PGC).
Source: Author's estimation, using Stata software.

Note: PGC is standardized, Spatial lagged PGC is the Spatial lag term of PGC, and it is also standardized according to the calculation of the adjacent space weight matrix. Moran's I is the slope of linear fitting between PGC and Spatial lagged PGC, and it is significant at 1 % level.

Appendix C

In this part, three classical spatial econometric models are used to regress PAC and PGC, respectively. The first is the Spatial Autoregression Model (SAR):

$$y = \lambda Wy + X\beta + \varepsilon \tag{17}$$

Where y represents the provincial innovation, Wy indicates the innovation weighted value of the neighboring provinces, λ measures the spillover effect of the neighboring provinces' innovation on the province, $X\beta$ means the core explanatory variable, and the control variable, ε is the spatial error term. The second is the Spatial Durbin Model (SDM):

$$y = WX\delta + X\beta + \varepsilon \tag{18}$$

$WX\delta$ represents the influence of the change of corporate income tax in the neighboring provinces on the innovation of the province, and other variables mean the same as before. The third is the Spatial Errors Model (SEM):

$$y = X\beta + \mu \tag{19}$$

$$\mu = \rho M\mu + \varepsilon \tag{20}$$

Where μ represents the error weighted value of neighboring provinces, ρ measures the influence of provincial error on innovation, and other variables are the same as before.

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