R&D expenditure in China: A structural change analysis

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Abstract

This paper investigates a possible structural change in R&D expenditure in China. Using province-level data for 1999–2019, four hypotheses are tested: the effect of GDP growth on R&D expenditure, the relationship between market competition and R&D expenditure, the crowding-out effect of real estate investment on R&D expenditure, and the impact of financial development on R&D expenditure. The main findings are as follows: (1) real GDP growth had a significantly negative effect on R&D expenditure in the first period (1999–2010) but a significantly positive effect in the second period (2010–2019), (2) market competition had a negative or no effect on R&D expenditure in the first period but a positive effect in the second period, (3) real estate investment crowded out R&D expenditure in the first period but had a crowding-in effect in the second period, (4) financial development facilitated R&D expenditure in the first period but had a negative effect in the second period, and real estate has acted as borrowing collateral in financial markets in recent years.

1. Introduction

The Chinese economy has experienced rapid economic growth since economic reform initiatives commenced in December 1978. The average annual growth rate of per capita real gross domestic product (GDP) was 8.6% from 1978 to 2017. However, Chinese economic growth has slowed recently. The annual growth rate of per capita real GDP in 2014 was 6.8%, which was the first time since the turn of the century that a growth rate below 7% had been recorded. The decline in GDP growth since 2010, the so-called “new normal” in China’s economic development, indicates a growth shift from quantity to quality in China. With these changes, innovation activities are assisting Chinese firms to

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develop a competitive advantage in recent years.

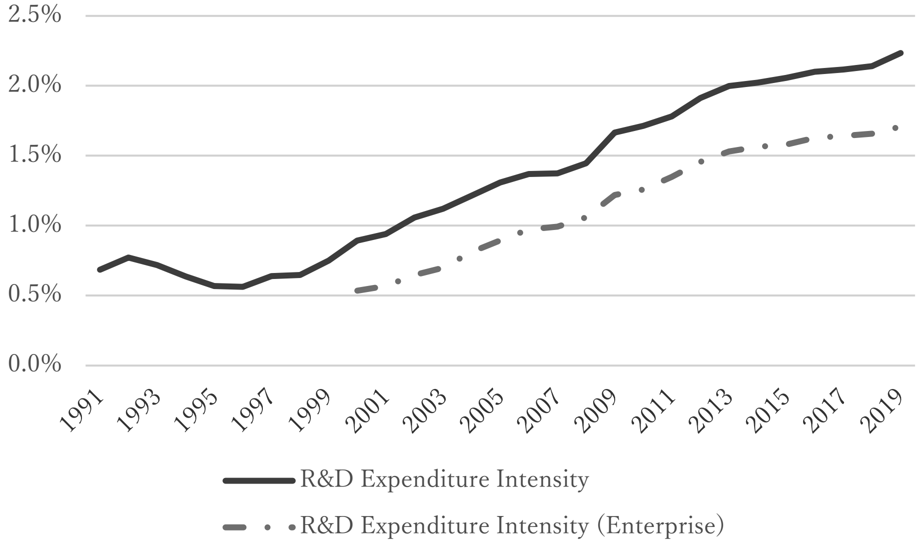
The purpose of this paper is to identify the causes of changes in R&D expenditure in China. More specifically, we examine the possibility of structural change in R&D expenditure as China transitions from a high-growth economy to one experiencing slower, albeit higher-quality, economic growth.

The Chinese economy has undergone significant changes in recent years with regard to R&D activity, both in terms of inputs and outputs. Figure 1 plots R&D expenditure intensity, which is defined as R&D expenditure as a share of GDP. The solid line shows the evolution of R&D expenditure intensity for the entire economy. In the 1990s, R&D expenditure intensity was stagnant and below 1%, but began increasing in 2000 reaching 2% in 2014 and 2.2% in 2019. The dotted line shows R&D expenditure intensity for enterprises, which has been rising consistently, reaching 1.7% in 2019. The figure shows that R&D expenditure has increased in recent years. Indeed, as shown in Chen et al. (2021), R&D intensity in China was similar to that in Canada in 2011 and is approaching the level of the United States. Figure 2 shows the share of the R&D expenditure by enterprise ownership type for the period 2011–2021. Limited liability corporations have always accounted for about a third of total R&D expenditure. This figure also confirms that the scale of R&D expenditure in private enterprises has been growing rapidly. These two series crossed in 2019, and the share of private enterprises jumped to about 39% in 2021, far exceeding that of other ownership firms. The number of personnel engaged in R&D in China has also been increasing. Figure 3 shows the number of personnel involved in R&D. There has been a marked increase in the number of personnel since 2000 at both the country and enterprise levels[(2)]. The polygonal line plots the rate of change in the number of R&D personnel. The rate of increase for enterprise mostly exceeds that of the whole society, suggesting that enterprise has become more interested in R&D since the 2000s and that investment activity has been more active.

Output from research and development activities has increased sharply. Figure 4 shows patent applications in China. Until 2000, the number of examined patent applications and certified patent applications had barely increased. However, the situation changed drastically after 2000. The numbers of examined patent applications and certified patent

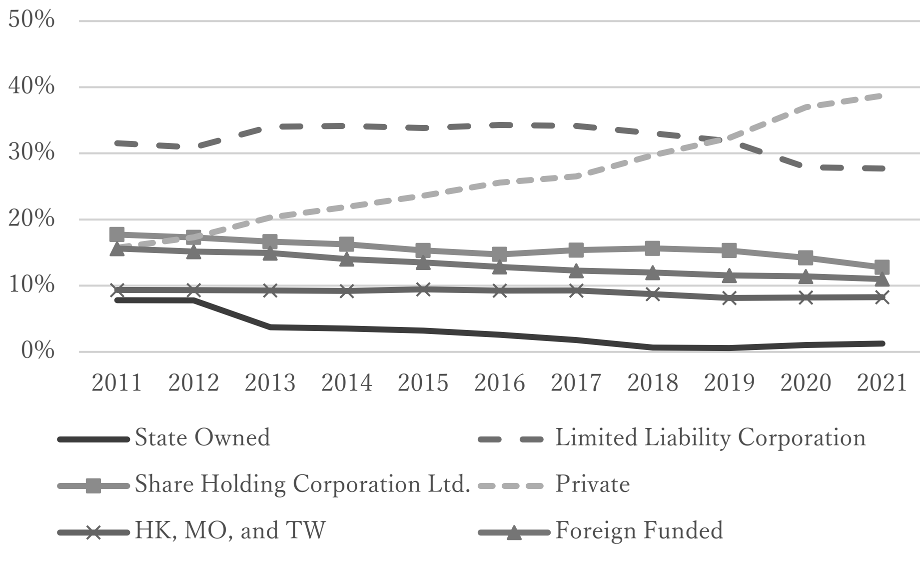
(2) According to China Statistical Yearbook (2020), R&D activities in China mainly include industrial corporate units above a designated size, industrial corporate units below a designated size, scientific research and technological development institutions and scientific and technological information and literature institutions at the prefecture level and above under the government with independent accounting, full-time universities and colleges, affiliated hospitals, and enterprises and institutions engaged in R&D activities in relatively R&D-intensive industries.

Figure 1. R&D expenditure intensity



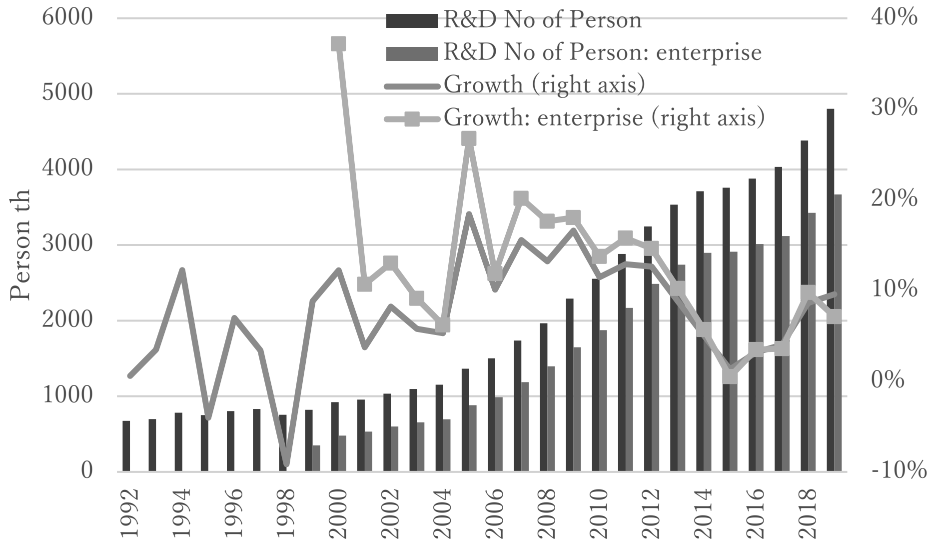
Source: China Statistical Yearbooks and CEIC China Premium Database.

Figure 2. The share of R&D expenditure by firm ownership in industrial enterprises



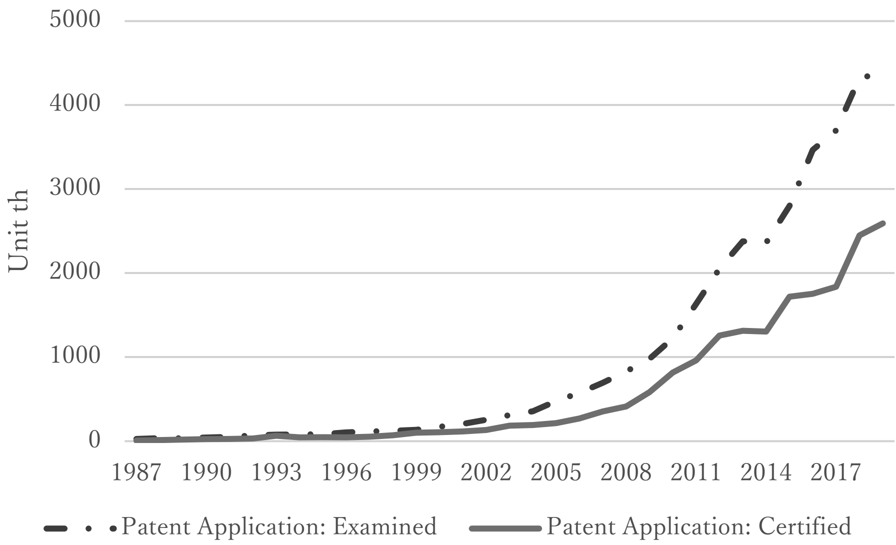
Source: CEIC China Premium Database.

Figure 3. Number of R&D personnel



Source: CEIC China Premium Database.

Figure 4. Patent applications in China



Source: CEIC China Premium Database.

applications have increased by 201 and 676 times, respectively, compared with the base year of 1987.

This paper analyzes the changes in R&D expenditure in China using fixed effects estimation techniques with provincial-level data. Unlike previous studies, this paper tests four hypotheses for R&D expenditure in China, namely, the effect of GDP growth on R&D expenditure, the relationship between market competition and R&D expenditure, the crowding-out effect of real estate investment on R&D expenditure, and the impact of financial development on R&D expenditure. Furthermore, compared with previous studies, the unique feature of this paper is that it examines whether there have been structural changes in R&D expenditure. We find that in the first period (1999–2010), the estimated coefficient of real GDP growth was significantly negative but became significantly positive in the R&D expenditure equation in the second period (2010–2019). Greater market competition led to less or no effect on R&D expenditure in the first period but to the opposite effect in the second period. Real estate investment crowded out R&D expenditure in the first period but crowded in R&D expenditure in the second period. In the first period, financial development facilitated R&D expenditure but had a negative effect in the second period. Finally, the combined synergistic effect of real estate investment and financial development on R&D expenditure was examined. Real estate has acted as borrowing collateral in financial markets in recent years.

The remainder of this paper is organized as follows. Section 2 provides a brief review and then presents the hypotheses tested in this paper. Section 3 describes the data and specification strategy. Section 4 discusses the regression results. Finally, Section 5 concludes and discusses our future research agenda.

2. Literature Review

This section provides a brief review of previous studies on R&D expenditure, focusing primarily on recent research findings.

2.1.1 Economic growth and R&D expenditure

Numerous studies have examined the relationship between economic growth and R&D expenditure. Falk (2007) used panel data for OECD countries from 1970 to 2004 to investigate the relationship between R&D spending in the high-tech sector and economic growth. He found strong positive effects on GDP per capita and GDP per hour worked on the ratio of business enterprises' R&D expenditures to GDP and the share of R&D expenditure in the high-tech sector. Bayarcelik and Taşel (2012) empirically examined the relationship between innovation and economic growth in Turkey using a panel data set of chemical firms listed on the Istanbul Stock Exchange between 1998 and 2010. Positive and significant relations between R&D expenditure and the number of R&D employees and the rate of economic growth were found. Kim (2011) investigated the effect of the R&D stock on economic growth in South Korea. The author estimated an R&D-based Cobb–Douglas production function from 1976 to 2009 and found that the contribution ratio of the total R&D stock to economic growth is about 35%. In addition, public and private R&D stocks explain about 16% and 19% of economic growth, respectively.

Xiong et al. (2020) studied the relationship between R&D expenditure and economic growth in China, using a panel data set from 1998 to 2013, and found that the relationship between R&D inputs, R&D outputs, and economic growth differs across regions and sectors. For example, most of the positive effects stem from nonperipheral regions and nonstate-owned sectors. Furthermore, the results of this paper indicate the complexity of the relationships between R&D effort and economic performance, and point to the important role of social filters in innovation and growth. Zilibotti (2017) focused on innovation-led growth in recent years in China. Based on firm-level data on R&D and productivity growth, the author concluded that a transformation toward innovation-led growth is on the way. However, there is also a significant misallocation of R&D expenditure. A combination of subsidies, guidelines, and public investments in technology parks will generate a large misallocation of R&D effort, therefore, reforms and financial development to make innovation a market-based outcome are indispensable for assuring effective R&D expenditure.

2.1.2 Market competition and R&D expenditure

In this subsection, we review the results of recent studies on whether market competition promotes or hinders R&D expenditure. Aghion et al. (2005) investigated the relationship between product market competition and innovation. The authors developed a model to identify an inverted-U relationship in a panel data set. In the model, competition discourages laggard firms from innovating but encourages neck-and-neck firms to innovate. There are also two additional predictions from the model, one is that the average technological gap between leaders and followers increases with the degree of competition. The other is the inverted-U, which is steeper when industries are more neck-and-neck.

Negassi and Hung (2014) reviewed innovation and types of competition, before conducting an empirical study. Their data set contained 612 public-sector firms and 3240 private-sector firms. They found that for public-sector firms, the competition index was not correlated with innovation output, however, the competition index was positively and strongly correlated with innovation output for private-sector firms.

Negassi et al. (2019) empirically estimated the relationship between innovation and competition. By introducing, national factors, knowledge, capital, competitors' R&D activities, sectoral characteristics, and R&D public policies, the relationship between competition and innovation is an inverted U-shape because of the simultaneous influence of two opposing forces ('Schumpeterian effect' and 'escape competition effect'). Furthermore, there is an inverted-U-shaped relationship between innovation and competition for public-sector firms but not for private-sector firms because of the high level of competition among private firms.

2.1.3 Effect of real estate investment on R&D expenditure

Many researchers have expressed concern that heated real estate investments may be having a negative impact on corporate R&D expenditure in China. Chen and Wen (2017) developed a theoretical model to demonstrate this possibility, in which a growing housing bubble can crowd out productive capital investment, thus prolonging the economic transition and reducing social welfare. In China, housing bubbles have enticed many productive and high-tech firms to reallocate resources from R&D to the real estate market. Rong et al. (2016), using manufacturing firm data in China for the period 1999–2007, found that house price appreciation negatively influences manufacturing firms' innovation propensities. After further investigation, they obtained two insights. Housing price appreciation stimulated firms to enter the real estate industry and a firm's invention patenting is negatively influenced subsequent to its real estate diversification, and the negative effect was more pronounced where housing price growth rates were higher.

Kuang et al. (2020) explored the effect of home purchase restrictions (HPR) on corporate innovation by non-real-estate firms using a data set of 1830 listed non-real-estate firms over the period 2009–2016. The authors concluded that HPR increase R&D expenditure in these firms by hindering real estate investment, particularly for non-high-tech firms.

Shi et al. (2016) investigated the crowding-out effect of real estate bubbles by estimating the impact of real estate prices on firms' R&D and patents. By using 419 non-real-estate listed firms in China, they argued that Chinese firms reduce their R&D expenditure and patents in a hot real estate market, which could be explained partially by managerial myopia.

2.1.4 Financial market development and R&D expenditure

Sound financial markets ensure efficient resource allocation. Mature financial markets also promote efficient R&D expenditure that leads to technological progress. Hsu et al. (2014) collected data for 32 developed and emerging countries for 1976–2006 and used a fixed effects identification strategy to investigate how the development of equity markets and credit markets affects technological innovation activities. They found that industries in countries with better-developed equity markets that are more dependent on external finance and that are more high-tech intensive exhibit a disproportionally higher innovation level. However, the development of credit markets appears to discourage innovation in such industries.

Pradhan et al. (2018), using data from 49 European countries for 1961–2014, conducted panel unit root and panel cointegration tests to examine the interaction between innovation, financial development, and economic growth. They found that both financial development and innovation affect economic growth in the long run, suggesting that policy should focus on financial development and innovation to boost economic performance.

Law et al. (2018) used the generalized method of moments method to examine the nonlinear relationship between financial development and innovation. Their data set contained 75 developed and developing countries for the period 1996 to 2010. They found an inverted U-shaped nonlinear relationship between financial development and innovation. Their empirical results indicated that financial development enhances innovation only up to a certain level, after which further development tends to reduce innovation. This paper also investigated the role of the quality of institutions in the relationship between financial development and innovation and found an inverted U-shaped relationship only for countries with high institutional quality, indicating that sound institutional quality is a prerequisite for financial development that benefits innovation.

Xiao and Zhao (2012) used World Bank data for over 28,000 firms from 46 countries to examine how financial development affects firm innovation. The main finding is that whereas stock market development significantly enhances firm innovation, banking sector development has mixed effects. Tadesse (2006) used a panel of 10 manufacturing industries across 34 countries for the period 1980–1995 and found that whereas market-based financial systems have a generally positive effect on innovations in all economic sectors, bank-based financial systems foster more rapid technological progress in more information-intensive industrial sectors, suggesting a heterogeneous impact of financial architecture. This paper concludes that these two distinct types of financial systems have differential effects on a country's innovative landscape according to the industrial structure of the economy. By using panel data for 77 countries over the period 1965–2009, Ang and Madsen (2012) found that countries with more developed financial systems are more innovative. A stronger patent protection framework, however, curbs innovative production. Zhu et al. (2020) found that an expansion of the financial sector may reduce the amount of innovative activity and hence innovation-led growth, using data for 50 countries for the period 1990–2016.

Whereas the existing literature on innovation is mainly limited to large public firms in developed countries such as the United States, Ayyagari et al. (2011) investigated firm characteristics associated with innovation in over 19,000 firms in 47 developing countries. The main finding is access to external financing is associated with greater firm innovation, measured by the introduction of new products and technologies, knowledge transfer, or new production processes.

2.2 The hypotheses

Based on the studies mentioned above, four hypotheses are tested in this paper. The first question is whether GDP growth is a contributor to R&D expenditure. The second is whether the degree of competition in the market stimulates R&D expenditure. The third is whether real estate investment crowds out or crowds in R&D expenditure. The final question is whether the development of financial markets facilitates R&D expenditure.

3. Data and Estimation Model

The aggregate data at the provincial level used for this empirical exercise are from the China Statistical Yearbook (several years) and the CEIC China Premium Database. Two data series are used as the explained variable, R&D expenditure. The first is R&D expenditure by an industrial enterprise at the provincial level. The second is the total provincial R&D expenditure. The former reflects firm activity and is most suitable for the research objectives of this study, whereas the latter is employed for a robustness check. To test the hypotheses presented above, we have chosen four main explanatory variables, real per capita GDP growth, nonstate industrial enterprise ratio (number of nonstate industrial enterprises /total number of industrial enterprises), real estate investment, and deposit to GDP ratio (total deposits in financial institutions in the province at year-end/GDP).

Seven additional explanatory variables are used: fixed asset investment, ratio of state firm revenue from principal businesses to GDP, ratio of fixed assets investment from Hong Kong, Macao, and Taiwan, and foreign-funded units to total fixed assets investment, ratio of imports to GDP, ratio of government expenditure to GDP, ratio of nonprimary industry output to GDP, and number of higher education graduates per 1,000 people.

We converted nominal R&D expenditure into real terms using the provincial consumer price index and converted real estate investment and fixed asset investment into real terms using the provincial fixed asset investment price index. The base year is 1999. The data interval in this exercise is 1999–2019. To test for structural change in R&D expenditure in China, we set 1999–2009 as the first period and 2010–2019 as the second period.

Table 1 reports the descriptive statistics. A total of 651 observations are available for the estimation period. R&D expenditure by enterprise and total provincial R&D expenditure in the second period are 5.8 times and 4.5 times larger than those in the first period, respectively. Real per capita GDP growth is about the same in the first and second periods but the growth rate is slightly slower in the second period. The number of nonstate firms is 1.2 times larger in the second period, indicating that the degree of competition in the market has intensified recently. The scale of real estate investment has increased rapidly. Average real estate expenditure is approximately 4.7 times higher in the second period than in the first period. This indicates the existence of a real estate investment boom in China. The deposit to GDP ratio is higher in the second period, meaning that financial markets have become more mature in recent years(3).

We estimate a standard fixed effects model:

$$Y_{i,t} = \alpha + \beta I_{i,t} + \gamma' \boldsymbol{X}_{i,t} + Year_t + \eta_i + \varepsilon_{i,t},$$

where subscript i indicates the province and t is the time index. $Y_{i,t}$ is the natural logarithm of real R&D industrial enterprise expenditure or the natural logarithm of real total R&D expenditure at the provincial level. $I_{i,t}$ are the four explanatory variables: real per capita GDP growth, nonstate industrial enterprise ratio, real estate investment, and deposit to GDP ratio. We estimate the model using each of these variables separately. $\boldsymbol{X}_{i,t}$ contains the seven additional control variables as explained above. $Year_t$ is a year dummy that controls annual macroeconomic effects and η_i is fixed province-specific effects. $\varepsilon_{i,t}$ is an idiosyncratic error term, which we assume follows the standard assumptions.

Fixed effects estimation has several advantages in the current exercise. First, potential endogeneity due to missing variables can be avoided. If some missing unobservable time-invariant components are correlated with the error term, then fixed effects transformations can eliminate these factors from the estimation. Second, using fixed effects estimation may avoid some estimation bias due to data quality. In fact, numerous studies have criticized the quality of official Chinese data(4). If the measurement error in the data can be viewed as time invariant component, we can control for the bias by applying fixed effects estimation.

(3) The extracted data set contained missing values. Missing values of the fixed investment price index for Guangdong (1999, 2000), Hainan (1999), and Tibet (all periods) are filled with national data. Fixed asset investment in 1999, 2018, and 2019 is calculated from annual growth rate data.

(4) One representative study is Holz (2004).

Table 1. Descriptive statistics

	1999–2019				
	Obs	Mean	Std. Dev.	Min	Max
Real R&D industrial enterprise expenditure (RMB mn)	651	122.2	223.8	0.00	1549.4
Real R&D expenditure (RMB mn)	651	189.4	300.7	0.09	2073.9
Real per capita GDP growth (previous year=100)	651	110.5	2.98	97.5	123.8
Ratio of non-state firm numbers	651	0.80	0.18	0.13	0.99
Real estate investment (RMB bn)	651	1.19	1.46	0.00	10.01
Ratio of deposit to GDP	651	1.59	0.67	0.75	5.38
Real total investment (RMB bn)	651	6.51	7.29	0.05	37.13
Ratio of state firm revenue from principal business to GDP	651	0.44	0.19	0.05	1.12
Share of investment from HK, MO, and TW, and foreign funded units	643	0.06	0.05	0.00	0.27
Ratio of import to GDP	651	0.14	0.22	0.00	1.34
Ratio of government expenditure to GDP	651	0.23	0.18	0.06	1.38
Ratio of non primary industry to GDP	651	0.88	0.07	0.64	1.00
Number of higher education graduates per 1,000 people	651	3.50	2.08	0.28	8.94

	1999–2009					2010–2019				
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
Real R&D industrial enterprise expenditure (RMB mn)	341	37.2	62.1	0.00	435.8	310	215.7	290.5	0.10	1549.4
Real R&D expenditure (RMB mn)	341	71.2	102.4	0.09	587.3	310	319.5	382.5	0.90	2073.9
Real per capita GDP growth (previous year=100)	341	111.7	2.52	105.1	123.8	310	109.1	2.90	97.5	117.4
Ratio of non-state firm numbers	341	0.71	0.21	0.13	0.99	310	0.89	0.08	0.55	0.99
Real estate investment (RMB bn)	341	0.43	0.50	0.00	2.46	310	2.03	1.69	0.00	10.01
Ratio of deposit to GDP	341	1.39	0.52	0.75	4.47	310	1.80	0.75	0.84	5.38
Real total investment (RMB bn)	341	2.43	2.44	0.05	14.43	310	11.01	8.15	0.36	37.13
Ratio of state firm revenue from principal business to GDP	341	0.46	0.18	0.05	0.96	310	0.42	0.20	0.05	1.12
Share of investment from HK, MO, and TW, and foreign funded units	335	0.07	0.06	0.00	0.27	308	0.04	0.04	0.00	0.18
Ratio of import to GDP	341	0.15	0.23	0.00	1.34	310	0.13	0.20	0.00	1.31
Ratio of government expenditure to GDP	341	0.18	0.13	0.06	1.07	310	0.28	0.21	0.11	1.38
Ratio of non primary industry to GDP	341	0.85	0.07	0.64	0.99	310	0.90	0.05	0.74	1.00
Number of higher education graduates per 1,000 people	341	2.24	1.77	0.28	8.65	310	4.89	1.41	1.99	8.94

4. Estimation Results

In this section, we report the estimation results. First, we will review the relationship between economic growth and R&D expenditure, then the relationship between market competition and R&D expenditure, real estate investment and R&D expenditure, and finally the relationship between financial market maturity and R&D expenditure.

4.1 Economic development and R&D expenditure

Whereas previous studies have focused on whether R&D contributes to economic growth, this study will examine whether economic growth promotes R&D in the expanding Chinese economy. Table 2 reports the estimation results. The estimated coefficient of GDP growth is not significant for either R&D expenditure by an enterprise or total provincial R&D expenditure over the entire period. Next, we review the results for the first and second subsample periods. Unlike the results for the entire period, the coefficient on GDP growth is negative and significant for the first period. By contrast, the coefficient is positive and significant for the second period. These results suggest that in the first period, there was less enthusiasm for R&D expenditure. China's economic growth pattern has been described as extensive growth during its fast-growth era, mainly due to capital investment[(5)]. It is believed that R&D expenditure leading to technological progress was neglected during this first period. However, in the second period, economic growth began to drive R&D expenditure, leading to a return to a growth pattern that promotes more advanced product development, given the limits of growth from capital investment. The results are similar for both explained variables, R&D expenditure by enterprise and total provincial R&D expenditure.

4.2 Market competition and R&D expenditure

Table 3 reports the estimation results of the relationship between market competition and R&D expenditure. In the full period estimates, we observe a significant inhibitory effect of the degree of competition in the market on R&D expenditure. Mixed results were confirmed for the subsamples. In the case of R&D expenditure by enterprise, although the estimated coefficient of the degree of market competition is significantly negative

(5) Extensive growth means that economic growth is a result not of technological progress but of growth in the use of the factors of production; for example, capital accumulation. The opposite concept, "intensive growth," refers to a pattern of growth through advances in production technology and desirable institutional design.

Table 2. Effect of GDP growth on R&D expenditure

	R&D industrial enterprise			R&D expenditure		
	whole period	first period	second period	whole period	first period	second period
GDP growth	–0.000	–0.030**	0.030**	–0.009	–0.034***	0.024***
	(0.013)	(0.013)	(0.011)	(0.012)	(0.010)	(0.007)
Investment	0.226***	0.637**	0.196**	0.180**	0.342***	0.195***
	(0.080)	(0.248)	(0.076)	(0.073)	(0.122)	(0.044)
State	0.218	0.507	0.123	–0.115	–0.026	0.049
	(0.273)	(0.507)	(0.280)	(0.245)	(0.307)	(0.185)
Foreign investment	0.318	1.761	0.342	0.130	1.304	0.223
	(1.331)	(1.439)	(1.585)	(1.119)	(1.207)	(1.091)
Import	0.095	0.798	–0.095	–0.180	0.271	–0.200
	(0.276)	(0.500)	(0.160)	(0.222)	(0.330)	(0.149)
Government expenditure	–3.129***	–4.955***	–1.795**	–1.414***	–1.582**	–1.964***
	(0.691)	(1.115)	(0.730)	(0.366)	(0.753)	(0.364)
Industrial structure	5.110***	2.421*	5.770***	3.950***	3.108***	3.220***
	(1.314)	(1.410)	(0.949)	(1.094)	(1.095)	(0.796)
Education	0.048	0.041	0.146**	0.033	0.058	0.098**
	(0.054)	(0.047)	(0.054)	(0.042)	(0.035)	(0.037)
Constant	–3.926**	–1.218	–6.693***	–0.971	1.221	–2.749***
	(1.439)	(1.583)	(1.531)	(1.136)	(1.440)	(0.903)
Observations	638	330	308	643	335	308
R-squared	0.954	0.908	0.832	0.965	0.943	0.911
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Number of provinces	31	30	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Table 3. Relationship between market competition and R&D expenditure

	R&D industrial enterprise			R&D expenditure		
	whole period	first period	second period	whole period	first period	second period
Competition	–1.350**	–1.032**	–0.803	–0.816*	–0.482	0.830*
	(0.519)	(0.446)	(1.063)	(0.470)	(0.349)	(0.476)
Investment	0.348***	0.592**	0.288***	0.236***	0.226*	0.201***
	(0.068)	(0.233)	(0.099)	(0.063)	(0.118)	(0.050)
State	0.044	0.460	0.245	–0.194	0.012	0.134
	(0.311)	(0.502)	(0.309)	(0.289)	(0.320)	(0.199)
Foreign investment	0.594	1.812	0.825	0.321	1.445	0.621
	(1.043)	(1.196)	(1.551)	(0.961)	(1.126)	(1.189)
Import	0.068	0.624	–0.292	–0.164	0.221	–0.336*
	(0.226)	(0.390)	(0.184)	(0.191)	(0.284)	(0.179)
Government expenditure	–2.473***	–4.341***	–1.750*	–1.188***	–1.454*	–1.998***
	(0.706)	(1.041)	(0.909)	(0.330)	(0.776)	(0.393)
Industrial structure	5.421***	2.258	6.378***	3.918***	2.927**	3.346***
	(1.228)	(1.489)	(1.200)	(1.039)	(1.206)	(0.776)
Education	0.035	0.029	0.125**	0.028	0.053	0.077*
	(0.050)	(0.044)	(0.052)	(0.040)	(0.035)	(0.039)
Constant	–4.358***	–3.601**	–3.824***	–1.888**	–1.354	–0.857
	(0.924)	(1.370)	(1.125)	(0.745)	(1.146)	(0.813)
Observations	638	330	308	643	335	308
R-squared	0.958	0.912	0.824	0.967	0.942	0.906
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Number of provinces	31	30	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

in the first period, the significance disappears in the second period. For total provincial R&D expenditure, we find a significantly positive effect in the second period for market competition on R&D expenditure. Based on the estimation results above, the following conclusions can be drawn. During the process of China's economic growth, the degree of competition in the market disincentivized R&D expenditure, but this effect has reversed in more recent years.

4.3 Real estate investment and R&D expenditure

In this subsection, we discuss the relationship between real estate investment and R&D expenditure. Since the implementation of the housing marketization policy, China has experienced extremely strong residential investment. Soaring housing prices have produced enormous returns on real estate investment. Many prior studies have expressed concern that high residential investment returns may negatively affect firms' regular investment activities. This study will examine whether real estate investment has a crowding-out or crowding-in effect on R&D expenditure. The results of the standard fixed effects model are presented in Table 4. First, the estimated coefficient of real estate investment is negative for the entire period, but not significant. For R&D expenditure by enterprise, the coefficients of real estate investment are significantly negative for both periods. These results indicate strong crowding out of R&D expenditure. However, we find a significantly negative effect in the first period and a positive but insignificant effect in the second period for total provincial R&D expenditure.

Fixed effects estimation can exclude potential endogeneity due to fixed factors that are time-invariant but cannot control endogeneity due to variables that are time-variant. We then estimate the model using the method of instrumental variables (IV estimation) to account for endogeneity concerns on the real estate investment variable. The two instrumental variables used here are the natural logarithm of real GDP and the natural logarithm of real disposable income per capita in urban areas at the provincial level. The estimation results are shown in Table 5. In contrast to the results of the fixed-effects estimation, a significant crowding-out effect was observed in the first period and a significant crowding-in effect was observed in the second period. In addition, similar results were obtained for both of the dependent variables, R&D expenditure by enterprise and total provincial R&D expenditure. These results suggest the possibility of structural changes in the relationship between real estate investment and R&D expenditure. In the early stages of economic development, real estate investment had a substitute relationship with R&D expenditure, such that when real estate investment occurred, R&D expenditure was avoided. However, real estate investment promoted R&D expenditure in recent years.

Table 4. Effect of real estate investment on R&D expenditure

	R&D industrial enterprise			R&D expenditure		
	whole period	first period	second period	whole period	first period	second period
Real estate investment	–0.106	–0.445**	–0.217**	–0.008	–0.197*	0.009
	(0.106)	(0.217)	(0.096)	(0.086)	(0.103)	(0.061)
Investment	0.297***	0.798**	0.403***	0.160*	0.304**	0.233***
	(0.098)	(0.292)	(0.077)	(0.086)	(0.139)	(0.051)
State	0.195	0.468	0.174	–0.114	–0.024	0.143
	(0.276)	(0.405)	(0.302)	(0.244)	(0.300)	(0.186)
Foreign investment	0.443	2.621*	0.894	0.096	1.718	0.611
	(1.313)	(1.482)	(1.482)	(1.121)	(1.260)	(1.183)
Import	0.086	0.770	–0.309	–0.156	0.281	–0.346*
	(0.274)	(0.467)	(0.194)	(0.218)	(0.329)	(0.180)
Government expenditure	–2.970***	–4.968***	–1.425	–1.444***	–1.486	–1.973***
	(0.816)	(0.791)	(0.985)	(0.392)	(0.928)	(0.456)
Industrial structure	5.572***	4.442**	7.122***	3.952***	4.207***	3.510***
	(1.674)	(1.649)	(1.528)	(1.264)	(1.265)	(0.967)
Education	0.050	0.042	0.129**	0.036	0.061*	0.079*
	(0.056)	(0.044)	(0.051)	(0.042)	(0.034)	(0.041)
Constant	–4.341***	–5.330***	–4.799***	–1.766*	–2.315**	–0.603
	(1.291)	(1.681)	(1.428)	(0.970)	(1.033)	(0.920)
Observations	638	330	308	643	335	308
R-squared	0.955	0.915	0.834	0.965	0.942	0.904
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Number of provinces	31	30	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Table 5. Effect of real estate investment on R&D expenditure (IV estimation)

	R&D industrial enterprise		R&D expenditure	
	first period	second period	first period	second period
Real estate investment	–0.896**	0.803**	–0.922**	0.720**
	(0.424)	(0.401)	(0.373)	(0.282)
Investment	1.033***	–0.316	0.764***	–0.256
	(0.314)	(0.270)	(0.278)	(0.196)
State	0.236	0.234	–0.224	0.284
	(0.298)	(0.388)	(0.222)	(0.254)
Foreign investment	3.348***	0.957	2.898***	0.462
	(1.186)	(1.819)	(1.038)	(1.184)
Import	0.577*	–0.128	0.143	–0.263**
	(0.302)	(0.189)	(0.216)	(0.120)
Government expenditure	–3.722***	–4.237***	–1.332**	–3.735***
	(1.134)	(1.182)	(0.647)	(0.833)
Industrial structure	6.238***	0.502	7.295***	–0.771
	(2.046)	(2.221)	(1.924)	(1.613)
Education	0.038	0.116*	0.050**	0.066
	(0.029)	(0.061)	(0.024)	(0.041)
Observations	360	277	366	277
R-squared	0.912	0.321	0.913	0.678
Fixed effect	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes
Hansen J	0.301	0.387	0.052	0.277
Number of provinces	30	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

The latter result will be discussed in depth in the next subsection.

4.4 Financial development and R&D expenditure

In the final subsection, we investigate the relationship between financial market development and R&D expenditure. First, no significant relationship was observed between financial market development and R&D expenditure for the full sample in Table 6. In the subsample periods estimation, although financial market development played a role in promoting R&D expenditure in the first period, it hindered it in the second period when the dependent variable was R&D expenditure by an enterprise. In other words, in the early stages of economic growth, financial market development supported R&D expenditure in China. However, despite a period of strong economic growth in China, the financial market lacks the financing function for R&D expenditure. For total provincial R&D expenditure, the financial market development variable is insignificant in both the first and second periods.

Next, we investigate the mutual effect of real estate investment and financial development on R&D expenditure. For this purpose, we introduce a new interaction term of real estate investment and financial development into the regression model. After controlling for this interaction effect, the estimated coefficients of financial development are significant and positive in the first period, confirming the positive effect of the financial market on R&D expenditure (Table 7). In the second period, there is no significant relationship between financial market development and R&D expenditure. The coefficients of the interaction term of real estate investment and financial development are significantly negative only in the first period. This indicates that during the development of financial markets, real estate investment crowds out R&D expenditure. Also, this occurs in the cases of the two dependent variables.

Considering that China' s financial markets have matured more recently, we adjusted the second period of the analysis to 2012–2019 and estimated the empirical model again. The estimation results are reported in Table 8. The positive effect of financial market development on R&D expenditure is still present in the first period, whereas the effect is negative in the second period. The results of the interaction term are quite interesting. In the first period, it is significantly negative, however, it becomes significantly positive in the second period. These results indicate that real estate has acted as borrowing collateral in financial markets in recent years[(6)]. As financial markets mature, Chinese commercial

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(6) Rong and Ni (2020) examined the listed R&D firms' R&D activities during the housing boom period 2002–2006 in the US and found that a $1 increase in real estate value leads a firm to increase its R&D

Table 6. Impact of financial development on R&D expenditure

	R&D industrial enterprise			R&D expenditure		
	whole period	first period	second period	whole period	first period	second period
Deposit	0.175	0.620*	–0.286**	0.081	0.274	–0.077
	(0.153)	(0.307)	(0.140)	(0.123)	(0.218)	(0.085)
Investment	0.284***	0.575**	0.219***	0.182***	0.210	0.230***
	(0.095)	(0.245)	(0.065)	(0.064)	(0.125)	(0.041)
State	0.166	0.640	0.437	–0.135	0.070	0.195
	(0.278)	(0.503)	(0.334)	(0.244)	(0.310)	(0.222)
Foreign investment	0.419	2.557*	1.594	0.138	1.727	0.818
	(1.312)	(1.362)	(1.626)	(1.116)	(1.297)	(1.248)
Import	0.033	0.553	–0.278	–0.183	0.188	–0.347*
	(0.258)	(0.414)	(0.180)	(0.211)	(0.296)	(0.171)
Government expenditure	–3.433***	–6.089***	–0.808	–1.615***	–2.077**	–1.695***
	(0.783)	(1.434)	(0.991)	(0.529)	(1.005)	(0.495)
Industrial structure	5.149***	2.492	5.769***	3.918***	3.205**	3.437***
	(1.277)	(1.567)	(1.243)	(1.076)	(1.215)	(0.888)
Education	0.053	0.024	0.119**	0.038	0.052	0.078*
	(0.054)	(0.050)	(0.050)	(0.041)	(0.037)	(0.040)
Constant	–4.495***	–4.830***	–3.284***	–1.987**	–1.998	–0.431
	(1.233)	(1.597)	(1.063)	(0.862)	(1.182)	(0.833)
Observations	638	330	308	643	335	308
R-squared	0.955	0.912	0.830	0.965	0.941	0.905
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Number of provinces	31	30	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Table 7. Mutual effect of real estate investment and financial development on R&D expenditure

	R&D industrial enterprise			R&D expenditure		
	whole period	first period	second period	whole period	first period	second period
Deposit	0.586	1.712***	–0.741	0.600	1.261***	–0.622
	(0.459)	(0.502)	(0.770)	(0.370)	(0.336)	(0.372)
Real estate investment	–0.015	–0.121	–0.317*	0.126	0.057	–0.114
	(0.135)	(0.143)	(0.169)	(0.132)	(0.101)	(0.125)
Deposit	–0.052	–0.179**	0.068	–0.068	–0.156***	0.072
× Real estate investment	(0.055)	(0.067)	(0.101)	(0.043)	(0.044)	(0.051)
Investment	0.310**	0.678***	0.391***	0.127	0.202	0.251***
	(0.118)	(0.204)	(0.072)	(0.097)	(0.120)	(0.057)
State	0.148	0.437	0.359	–0.102	–0.010	0.223
	(0.279)	(0.410)	(0.319)	(0.232)	(0.272)	(0.208)
Foreign investment	0.475	2.795**	1.546	0.104	1.794	0.882
	(1.292)	(1.330)	(1.576)	(1.066)	(1.248)	(1.274)
Import	0.000	0.790	–0.176	–0.187	0.429	–0.211
	(0.248)	(0.514)	(0.280)	(0.216)	(0.329)	(0.166)
Government expenditure	–3.579***	–6.027***	–0.358	–2.292***	–2.532**	–1.360**
	(0.905)	(0.832)	(0.910)	(0.733)	(0.959)	(0.559)
Industrial structure	5.356***	3.036**	6.786***	3.342**	2.656**	3.465***
	(1.643)	(1.413)	(1.626)	(1.318)	(1.054)	(1.031)
Education	0.054	0.041	0.122**	0.031	0.063*	0.075*
	(0.056)	(0.039)	(0.046)	(0.042)	(0.033)	(0.038)
Constant	–4.974***	–5.780***	–3.638*	–1.880*	–2.073**	0.137
	(1.478)	(1.303)	(1.915)	(1.012)	(0.944)	(1.044)
Observations	638	330	308	643	335	308
R-squared	0.956	0.923	0.840	0.966	0.948	0.907
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Number of provinces	31	30	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Table 8. Mutual effect of real estate investment and financial development on R&D expenditure (second period commences from 2012)

	R&D industrial enterprise		R&D expenditure	
	first period	second period	first period	second period
Deposit	2.040***	–1.430***	1.208***	–0.913***
	(0.494)	(0.451)	(0.413)	(0.328)
Real estate investment	0.066	–0.605***	0.143	–0.222**
	(0.128)	(0.144)	(0.097)	(0.107)
Deposit	–0.220***	0.166***	–0.140***	0.110**
× Real estate investment	(0.063)	(0.059)	(0.050)	(0.043)
Investment	0.491**	0.448***	0.124	0.272***
	(0.184)	(0.081)	(0.114)	(0.057)
State	0.088	0.080	–0.074	0.187
	(0.342)	(0.379)	(0.290)	(0.272)
Foreign investment	2.109	1.763	1.491	1.152
	(1.440)	(1.975)	(1.275)	(1.338)
Import	0.601	0.108	0.225	–0.141
	(0.531)	(0.191)	(0.327)	(0.136)
Government expenditure	–4.533***	–1.051	–2.843***	–1.760***
	(0.946)	(0.890)	(0.762)	(0.607)
Industrial structure	2.002	5.264**	1.789	2.555*
	(1.709)	(1.980)	(1.156)	(1.361)
Education	0.046	0.111**	0.043	0.064*
	(0.040)	(0.042)	(0.035)	(0.034)
Constant	–4.673***	0.044	–1.124	1.965
	(1.593)	(2.136)	(1.098)	(1.474)
Observations	392	246	397	246
R-squared	0.939	0.711	0.955	0.859
Fixed effect	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes
Number of provinces	31	31	31	31

Robust standard errors are shown in parentheses. The symbols ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

banks are likely to require collateral borrowing to avoid the risk of bankruptcy on risky R&D investments.

5. Conclusion

This paper analyzed changes in R&D expenditure in China. We examined the issue from four main perspectives: the effects of economic growth, market competition, real estate investment, and financial market development. In particular, we examined whether structural changes have occurred with respect to R&D expenditure. The main results are as follows. In the first half of the estimation period, the estimated coefficient of real GDP

expenditure by $0.38. Mao (2021), using data from Compustat firms in the US from 1990 to 2010, also found that appreciation in the value of corporate real estate assets can alleviate financing constraints for innovation by allowing firms to issue additional secured debt.

growth was significantly negative, greater market competition led to less or no effect on R&D expenditure, real estate investment has a crowding out effect on R&D expenditure, and financial development facilitated R&D expenditure. However, we found opposite results in the second estimation period. We also investigated the interaction effect of real estate investment and financial development on R&D expenditure, the results indicating that real estate has acted as borrowing collateral in financial markets in recent years.

However, there are also several shortcomings and limitations to the analysis in this paper. Chen et al. (2021) showed the possibility of a significant increase in reported R&D expenditure due to changes in the tax system. China's InnoCom program provides substantial corporate income tax cuts to firms that report R&D expenditure above a certain threshold. This program produces very large incentives for firms to increase reported R&D expenditure. After 2008, by relaxing the R&D intensity rate (R&D expenditure as a proportion of revenue), they found large increases in R&D expenditure of 25 percent for large firms, 17 percent for medium firms, and 10 percent for small firms in 2011. Future estimates should remove the impact of this tax system change. The study in this paper used aggregated province-level data. It is difficult to obtain information on corporate decision making. In addition, R&D expenditure may be affected by differences in ownership structure. To resolve the above shortcomings, future research using corporate-level data is necessary. Furthermore, in this paper, we arbitrarily divided the study period into two subsamples and reestimated our model. Future research should verify the timing of structural changes using, for example, the Chow test (Chow, 1960). Finally, if structural changes in R&D expenditure behavior in China are observed, as indicated in this paper, it is desirable to develop a theoretical model that can describe this phenomenon.

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