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Innovation investment and sustainable development

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Abstract. Innovation and technological progress are essential approaches to sustainable growth, but what will affect enterprises' innovating motivation hasn't been thoroughly analyzed. We establish an endogenous growth model to analyze the factors that influence an enterprise's innovation investment, and find that the cumulative technology plays a key role: the more cumulative technology an enterprise has, the more its R&D investment will be. Empirical researches confirm the theoretical conclusions. Our study provides suggestions for policies to promote technological progress and sustainable development.

1 Introduction

Sustainable growth means increasing output with less resource consumption and environmental pollution, and innovation is the key factor for industries to achieve sustainable growth. Innovation can bring about breakthrough technological progress and incremental technological progress [1].

Enterprises are the main promoters of innovation [2-4], so it is essential to increase the R&D investment and R&D motivation of enterprises, not only for the industry but also for the whole economy. Many types of research have been conducted on the influencing factors of the R&D investment of enterprises, but these studies are not sufficient.

Early studies emphasized the role of enterprise size, and they believed that only large enterprises are capable of innovation [5-7]. Later, the influence of market structure was widely discussed that enterprises can achieve higher profits from innovation in a monopoly market than in a competitive market [8]. Other studies have analyzed the impact of credit, patents, and executives [9-11].

But the role of an enterprise's accumulative technology haven't been fully emphasized. The cumulative technology is defined that a new round of innovations is built on the last-round one [12], and each enterprise takes its own technology as the starting point of R&D. As the leading enterprises have more cumulative technology than the laggings, their starting point of innovation is higher, making it easier to obtain the most advanced products. On the contrary, backward enterprises have a low starting point of innovation, making it hard to reach the frontier level, and they can only produce low-end products. Due to the fierce competition among low-end products, it is difficult for backward enterprises to obtain sufficient profits from innovation, so their R&D willingness may be relatively low. Therefore, an enterprise's cumulative technology may positively impact its R&D investment.

However, although some studies have highlighted the importance of cumulative technology [13,14], the analysis of whether the enterprise's cumulative technology promotes its R&D investment is insufficient.

We set up an endogenous growth model, which enables enterprises to maximize their net profits by selecting the optimal R&D investment, with cumulative technology as the starting point of innovation. Through these Settings, we theoretically analyze the impact of the enterprise's cumulative technology on its R&D investment. Then, we use the data of China's listed manufacturing companies from 2012 to 2018 to verify the results of theoretical research.

The contribution is, in the classical quality-ladder model, technology spillover is perfect in innovation, so all enterprises play the same role in technological progress. In this paper, we find that the leading enterprises are the main pushers of the industrial technology growth.

2 The model

We build our theoretical model based on the quality-ladder model [15,16], but some settings are adjusted: firstly, the technological difference of intermediate goods is made to be reflected in the quality, so as to make the intermediate goods with different technological levels all be demanded by the market, and make the technical level be positively correlated with its price; secondly, the setting of perfect technology spillover in the innovation is canceled, and enterprises are assumed to conduct innovation depending on their own technology; last, since all the enterprises have chances to achieve technological progress, the setting of Poisson arrival rate is canceled and the method of Jones [17] is used to make the range of technological advancement of enterprises related to their R&D investment.

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The final goods are competitive and homogeneous, used for capital investment, R&D investment, and family consumption, and serve as unit price. The production function of final goods and the demand for intermediate goods i are respectively:

$$Y_t = (\sum_{1}^{M_t} A_{i,t} X_{i,t}^{\rho})^{\frac{1}{\rho}} \quad (1)$$

$$P_{i,t} = Y_t^{1-\rho} A_{i,t} X_{i,t}^{\rho-1} \quad (2)$$

where M_t means the number of intermediate goods firms, $A_{i,t}$ refers to the quality level of intermediate goods i, and ρ reflects the elasticity of substitution between different intermediate goods. All the intermediate goods are produced by capital $K_{i,t}$ and labor $LP_{i,t}$ with the Cobb-Douglas production function:

$$X_{i,t} = K_{i,t}^{\alpha} (LP_{i,t})^{1-\alpha} \quad (3)$$

The technology of enterprise i comes from R&D. Taking the cumulative technology $(A_{i,t-1})$ at the end of the last period as the start point, enterprise i has to invest in R&D to obtains current technology $(A_{i,t})$, and the R&D input is researchers $(LR_{i,t})$. It is assumed that each enterprise's initial technology is far higher than 0 $(A_{i,t-1} \gg 0)$.

$$A_{i,t} = A_{i,t-1}^{\gamma} (\delta LR_{i,t}^{\varepsilon} + 1) \quad (4)$$

where δ is the R&D efficiency, γ and ε are the elasticities of cumulative technology and R&D investment, respectively. To avoid explosive technology growth, we set $0 < \gamma \leq 1$ and $0 < \varepsilon < 1 - \rho$. The net profit $\pi_{i,t}^*$ is the result of output minus factor costs and R&D investment:

$$\pi_{i,t}^* = P_{i,t} X_{i,t} - r_t K_{i,t} - w_t LP_{i,t} - w_t LR_{i,t} \quad (5)$$

Enterprises choose optimal R&D investment with the goal of achieving maximum net profit. But, due to the market products being substituted for each other, each enterprise is facing the market environment of monopolistic competition. The influence of market environment on enterprise's production can be presented by parameter Φa:

$$\pi_{i,t}^* = \Phi B_t A_{i,t}^{\frac{1}{1-\rho}} - w_t LR_{i,t} \quad (6)$$

where $B_t = (\frac{1-\alpha}{w_t})^{\frac{(1-\alpha)\rho}{1-\rho}} (\frac{\alpha}{r_t})^{\frac{\alpha\rho}{1-\rho}} Y_t$, and is exogenous for each enterprise. Equation 6 shows that the higher the technical level of enterprise i, the larger the size. Assume that enterprise i cannot realize the effect of its R&D on its market power, that means enterprise i will take Φ as an exogenous variable. It's easy to prove that endogenous Φ doesn't change the main conclusion. The first-order condition of R&D investment is:

$$\frac{\Phi B_t}{1-\rho} A_{i,t-1}^{\frac{\gamma}{1-\rho}} (\delta LR_{i,t}^{\varepsilon} + 1)^{\frac{\rho}{1-\rho}} \varepsilon \delta LR_{i,t}^{\varepsilon-1} = w_t \quad (7)$$

As $A_{i,t-1} \gg 0$, then $LR_{i,t} \gg 1$, and equation 7 can be transformed into:

$$\ln(LR_{i,t}) \approx \frac{\gamma}{1-\varepsilon-\rho} \ln(A_{i,t-1}) + constants \quad (8)$$

then take the partial derivative of the logarithm of cumulative technology with respect to equation 8:

$$\frac{\partial \ln(LR_{i,t})}{\partial \ln(A_{i,t-1})} \approx \frac{\gamma}{1-\varepsilon-\rho} \quad (9)$$

Equation 9 means that the more cumulative technology an enterprise has, the more its R&D investment will be.

3 Empirical tests

We will verify the factors that influence the R&D investment of enterprises.

3.1. Data and indexes

Data: We select the data of manufacturing listed companies from 2012 to 2018 in China, and exclude the companies for whom more than 30% of data is missing. This leaves us with 627 companies.

Index: (1) Cumulative technology includes industrial public knowledge and the enterprise's private knowledge. In the theoretical part, we assume that all technology is private, but in reality, the early years' technology of the industry is often shared by all enterprises, and the newly developed technology is monopolized by its creator. Combining this with the available years of data leads us to assume that the patent in the last two years is the enterprises' private cumulative technology. The patents in the earlier years are public knowledge shared by the industry. Referring to Dosi et al. [18] and Tong et al. [19], we use the number of patent applications to measure cumulative technology. Although patents may not always be granted, the index is a good indicator of the innovation output of the year. (2) R&D input is represented by R&D expenditure [20,21]. Although the number of researchers is used in the theoretical model, changing the input to expenditure does not change the theoretical conclusions. Moreover, most companies do not disclose the researchers' data, and R&D expenditure is the only relevant data available. (3) Control variables include enterprise age, capital structure, marketability, and executive compensation [19,22]. And according to the discussion above, we add enterprise-size and market share supplementarily. Data descriptions are shown in Table 1 below.

Table 1. Descriptive analysis.

Variable	Name	Variable description
RDinves	R&D investment	Ln (R&D expenditure)
cumte	cumulative technology	Ln (patents applied in the previous two years)
cr	market share	Sales/industry sales
size	size	Ln (total assets)

[a] $\Phi = (1-\varphi)\rho^{\frac{\rho}{1-\rho}}$. When an enterprise's market power approaches 1, then $\varphi \to \rho$ and the enterprise profit is maximum; When an enterprise's market power approaches 0, then $\varphi \to 1$ and there is no profit in production.

age	age	Ln (enterprise age)
alr	capital structure	Asset-liability ratio
mc	market capacity	Sales expenses/total revenue
tmtw	executive compensation	Total executive income

3.2 Empirical model specification

According to the theoretical model, the greater the cumulative technology, the greater the investment of R&D. We will verify it in this section. In Model 1, we control the common factors that influence an enterprise's R&D investment and add its size and cumulative technology. Then, in Model 2, the interaction item of enterprise size and cumulative technology is added to analyze the adjustment effect on innovation.

Model 1:

$$RDinves_{i,t} = cumte_{i,t} + size_{i,t} + cr_{i,t} + age_{i,t} + alr_{i,t} + mc_{i,t} + tmtw_{i,t} \quad (10)$$

Model 2:

$$RDinves_{i,t} = cumte_{i,t} + size_{i,t} + cumte_{i,t} * size_{i,t} + cr_{i,t} + age_{i,t} + alr_{i,t} + mc_{i,t} + tmtw_{i,t} \quad (11)$$

3.3 Empirical results and analysis

See Table 2 below for the regression result of Model 1 and Model 2, where *, ** and *** refer to 10%, 5% and 1% significant level, respectively.

In Model 1, both the coefficient of enterprise size and the cumulative technology are significantly positive. It confirms the theoretical conclusion: bigger and more technologically advanced enterprises have greater R&D investment. It is also found that size plays a much more significant role in R&D investment than cumulative technology: the regression coefficient of size is 0.9112, while that of cumulative technology is 0.1352. It seems to show that R&D is mainly driven by size, and the innovation motivation brought by the technological advantage is limited. But after the interaction item is added, the conclusion has changed.

In Model 2, the coefficient of enterprise size and the cumulative technology are also significantly positive, and the coefficient of size increases little compared with Model 1 (from 0.9112 to 1.1856). In contrast, cumulative technology's coefficient rises more than 14 times (from 0.1352 to 1.9487). It demonstrates that the effects of cumulative technology and size rely on each other, and the role of cumulative technology is more dependent on size. A bigger cumulative technology needs a larger enterprise size so as better to promote the enterprise’s R&D, and vice versa. Moreover, with the cooperation of enterprise size, cumulative technology has a more significant impact on R&D investment than size. The conclusion is easy to understand. If the enterprise with advanced technology is small in size, it is difficult to bear the enormous investment in R&D even if it has strong R&D motivation. On the contrary, if the enterprise with advanced technology has a large scale, the R&D motivation brought by technological advantages can play a full role. The coefficient of the interaction item is significantly negative, but the value is small. It indicates that when an enterprise has dual advantages of size and technology, its R&D investment will decline slightly. With dual advantages of size and technology, the enterprise is hard to meet real challenges, so the sense of crisis about R&D falls, which goes against innovation investment.

In terms of control variables, the effect of the market share of an enterprise on its R&D investment is the largest among all the factors, and is also more extensive than that of cumulative technology. The coefficient of market share is 4.1596 in Model 1 and 4.6388 in Model 2. A high market share is helpful for enterprises to strengthen pricing power and profitability. In order to gain market share, enterprises are motivated to invest in R&D to improve their technological level. The coefficients of market capacity are 1.9331 in Model 1 and 1.7594 in Model 2, which are similar to that of cumulative technology. The market capability reflects the ability of an enterprise to turn innovation into profits. Since profit is the fundamental goal of R&D, the R&D motivation of an enterprise is higher under stronger market capacity. The age and executive compensation of an enterprise also have positive impacts on its R&D investment. The older the enterprise is, the higher the executive level, and the more experience the enterprise has. While the high debt ratio of an enterprise means that it has less liquidity, and its R&D investment is restrained accordingly.

Table 2. Influencing factors of R&D investment.

	Model 1	**Model 2**
size	0.9112 * * *	1.1856 * * *
	(0.0441)	(0.0617)
cumte	0.1352 * * *	1.9487 * * *
	(0.0218)	(0.2878)
cumte * size		-0.0819 * * *
		(0.0130)
cr	4.1596 * * *	4.6388 * * *
	(1.4087)	(1.3999)
mc	1.9331 * * *	1.7594 * * *
	(0.4330)	(0.4306)
age	0.2351	0.4710 * *
	(0.1840)	(0.1864)
alr	-0.2691 * *	-0.2766 * *
	(0.1214)	(0.1205)
tmtw	0.0020 * * *	0.0019 * * *
	(0.0007)	(0.0007)
N	3135	3135
r2_a	0.2796	0.2909

3.4 Robustness Analysis

In order to make sure that the conclusion of empirical research is robust, we change the core variable and set the number of patents of enterprises in the last period as the cumulative technology to compare the difference with the previous findings. The results of the regression are shown in Table 3 below. The main conclusions are consistent with the original model (Table 2), but there are also slight differences.

Enterprise size has a significant positive influence on R&D investment, and the regression coefficient thereof in Model 2 (1.1459) is slightly higher than that in Model 1 (0.9694), which is basically consistent with the previous conclusion. The coefficient of cumulative technology is significantly positive, and the coefficient in Model 2 is much greater than that in Model 1, which is also consistent with the previous conclusion. However, in the current results, the coefficients of cumulative technology are 0.0967 in Model 1 and 1.5988 in Model 2, which are significantly smaller than the previous regression coefficients (0.1352 in Model 1 and 1.9487 in Model 2). It means that the more the cumulative technology, the greater the effect on R&D investment. Moreover, the interaction term's regression coefficient between scale and cumulative technology is still negative, but the inhibiting effect on R&D investment (-0.0678) is slightly lower than the previous results (-0.0819). That is in line with the conclusion before.

After the core indicators are changed, the cumulative technology is declined, resulting in the decline of leading enterprises' technological advantages, and further leading to the decrease of the degree of inhibition on R&D investment. Among the control variables, the coefficient of market share is lower than the previous result (current: 2.7715 in Model 1 and 3.2694 in Model 2; previous: 4.1596 in Model 1 and 4.6388 in Model 2), which shows that the market share of leading enterprises can do better in promoting R&D investment when the advantage of cumulative technology is greater. The regression result of market capacity is close to the previous one. Although the regression results of enterprise age, debt ratio, and executive compensation have some changes compared with previously, the values are small. It means they have little impact on R&D investment, so no more discussion here.

Table 3. Robustness test.

	Model 1	Model 2
size	0.9694***	1.1459***
	(0.0380)	(0.0468)
cumte	0.0967***	1.5988***
	(0.0161)	(0.2361)
cumte*size		-0.0678***
		(0.0106)
cr	2.7715**	3.2694***
	(1.2152)	(1.2101)
mc	1.9021***	1.7990***
	(0.3841)	(0.3820)
age	0.0952	0.2659*
	(0.1423)	(0.1439)
alr	-0.3031***	-0.2943***
	(0.1089)	(0.1082)
tmtw	0.0015**	0.0014**
	(0.0006)	(0.0006)
N	3762	3762
r2_a	0.3083	0.3171

To sum up, the regression results show that an enterprise's cumulative technology has a significant effect on its R&D investment. Therefore, leading enterprises are the primary undertakers of industrial innovation.

4 Conclusions

We analyze the relationship between cumulative technology and the innovation investment of enterprises. By assuming that enterprises start R&D from their own cumulative technology and maximize net profit as the R&D's goal, we figure out how enterprises with different cumulative technology select their optimal R&D investment theoretically. The research shows that enterprises with stronger cumulative technology have larger R&D investment. Later, we use the data from China's listed companies in the manufacturing industry from 2012 to 2018 to confirm the theoretical results.

Therefore, in making the R&D subsidy policies, the fund shall incline the enterprises with leading technology to take full advantage of their cumulative R&D and make R&D funds more effective. Besides, it can also avoid intensifying the repeated research of backward enterprises. Furthermore, due to the fact that when an enterprise has the dual advantages of technology and size, its R&D motivation may decline, it is essential to maintain an appropriate competition between leading enterprises to promote technological progress and sustainable development.

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