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Performance Negative Feedback and Firm's R&D Efficiency: Moderating Roles of Regional Institutional Environment

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ABSTRACT

Based on the behavioral theory of the firm, we investigate the impact of performance negative feedback on R&D efficiency. The results show that when performance falls below aspirations, firms pay more attention to R&D projects with high R&D efficiency to get rid of the operating pressure, reputation pressure and resource constraints caused by the decline in performance. This effect may be influenced by institutional differences. In the case of negative feedback, a good regional institutional environment is conducive to the improvement of R&D efficiency, while a weak regional institutional environment weakens this effect. Specifically, the higher the degree of IPR enforcement and financial market development, as well as the lower the degree of local government intervention, the more inclined firms are to increase R&D efficiency. The findings provide insights into understanding R&D efficiency improvement in the context of emerging markets.

KEYWORDS

Performance Negative Feedback; Aspirations; R&D Efficiency; Institutional Environment

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1. Introduction

As China's economic development enters a "new normal" period, the role of research and development (R&D) in the competitiveness of enterprises and long-term economic growth is becoming increasingly prominent. Compared with similar firms without R&D, firms engaged in R&D activities tend to grow more rapidly (Anandarajan, Chin, Chi and Lee, 2007). Especially in today's increasingly competitive international market environment, R&D largely determines the success or failure of a firm. However, R&D activities are subject to uncertainty and incomplete exclusivity, which discourage firms from participating in R&D activities (Oliviero, 2017). How to motivate firms to actively engage in R&D activities has always been an important topic discussed by scholars, and the behavioral theory of the firm provides a new breakthrough point for this issue.

The behavioral theory of the firm holds that the gap between actual performance and aspiration level affects the economic decisions of individuals and organizations. When performance falls below the aspiration level (negative performance feedback), bounded rational decision makers define negative feedback as a state of "loss" or "dissatisfaction" that drives firms to conduct problemistic searches in order to raise performance above aspirations. Corresponding, the firm's risk tolerance has also improved, stimulating firms' willingness to increase R&D (Kahneman and Tversky, 1979; Greve, 2003; Lv et al.,2019).

Existing studies have assessed the impact of negative feedback on R&D investment (Chen and Miller, 2007; Lucas, Knoben and Meeus, 2018; Lv et al.,2019; Han, 2022; Madadian and Broeke, 2023). However, little attention has been paid to the impact of negative feedback on R&D efficiency. The success of innovation-driven development of firms depends not only on the continuous increase of R&D inputs, but also on the improvement of R&D efficiency, because the best measurement of outcomes of technological innovations is through the efficiency with which they are developed (Cruz-Cázares, Bayona-Sáez and García-Marco, 2013). In fact, the increase in R&D investment has not brought about a significant improvement in technological level due to the low R&D efficiency. The research on R&D efficiency helps us to understand the input-output process of technological innovation activities more clearly, as well as the institutional constraints of the process. For performance negative feedback, with the widening gap of performance below the aspiration level, resource constraints continue to intensify, limiting the resource input of firms engaged in R&D (Lv et al., 2019). Therefore, in the case of lower than aspirations, how to improve the R&D efficiency of firms and give full play to the utilization efficiency of existing resources has become a prominent issue to be solved urgently under the background of innovation-driven development strategy.

In addition, the impact of institutional differences on R&D efficiency should not be ignored. Institutional differences exist not only between countries, but also between different regions within a country. Compared with market economies with well-established institutions, such differences are particularly obvious in transition economies. Taking China as an example, due to its vast territory and huge population size, the significant differences in historical conditions, resource endowments and geographical transportation among different regions have led to unbalanced institutional development. 'There are very significant differences in the degree of local government intervention, intellectual property rights (IPR) enforcement, and financial market development in different regions in China. These institutional factors have an important impact on the decision-making behavior of firms (Peng, Sun, Pinkham and Chen, 2009). R&D activities are also inevitably affected by institutional factors (Levechenko, 2007).

Based on the behavior theory of the firm, we use DEA model to measure the R&D efficiency of firms, and explore the impact of negative feedback on R&D efficiency. The results show that performance below the desired level prompts firms to pay more attention to the R&D projects with high R&D efficiency, because negative feedback forces firms to engage in R&D projects that quickly bring market effect and commercial value, so as to get rid of the operating pressure, reputation pressure and resource constraints brought by the decline in performance. This effect may be influenced by institutional differences. In the case of negative feedback, compared with a weak institutional environment, a good regional institutional environment is more conducive to firms to improve their R&D efficiency.

Specifically, the degree of IPR enforcement and financial market development are significantly positively correlated with R&D efficiency, while the degree of government intervention is significantly negatively correlated with R&D efficiency.

The main reasons why we select China as the background are as follows: First, in line with many developing countries, China's R&D activities are in the exploratory development stage. Our study can provide a reference for the development of R&D activities in other developing countries. Moreover, China is still the largest developing country and the second largest economy in the world. The study of performance negative feedback on R&D efficiency of Chinese firms can help to understand emerging markets. Second, unlike developed countries such as the United States, which have a well-developed institutional environment (Peng, Ahlstrom, Carraher and Shi, 2017) conducive to corporate R&D, China is a vast country with many provinces, and the level of institutional development varies greatly from region to region. Studying the impact of China's institutional environment on corporate R&D activities provides institutional insights for other developing countries to promote R&D activities.

This paper contributes to the literature in the following ways. First, the existing literature on performance feedback and R&D investment mainly focuses on the R&D input stage, while less attention is paid to R&D efficiency. Taking R&D input to output as a systematic process, this study provides the first empirical evidence of negative feedback on R&D efficiency, which helps to promote the relevant research from the R&D input stage to the overall process, and extends previous research on performance feedback and R&D efficiency. Second, considering the potential impact of regional institutional environment on R&D activities, we further investigate the impact of institutional factors on the relationship between negative feedback and R&D efficiency. Our study enriches the existing literature on institutional factors and provides an empirical basis for effective government support the R&D activities of firms.

The remainder of this paper is organized as follows. Section 2 proposes hypotheses development. Section 3 provides research methodology. Section 4 presents empirical results. Section 5 concludes.

2. Hypothesis Development

2.1. Negative feedback and R&D efficiency

The behavioral theory of the firm provides a theoretical basis for the determinants of organizational search and change. The theory states that decision-makers make subsequent strategic changes by evaluating the gap between the current actual performance and the aspiration level. When performance falls below aspirations, bounded rational decision makers define negative feedback as a state of "loss" or "dissatisfaction" that drives firms to engage in problemistic search to find alternative solutions to low performance (Greve, 2003). Problemistic search is often combined with strategic changes as a decline in performance indicates problems in resource allocation, management model, or market strategy (Greve, 2003), and appropriate changes help a company improve its performance above aspirations. As the gap between performance below aspirations increases, the breadth and intensity of problemistic search increases, the motivation and degree of strategic change also increase (Kahneman and Tversky, 1979; Lv, Chen, Zhu and Lan, 2021; Madadian and Broeke, 2023), which may have a positive impact on R&D efficiency.

First, organizations and decision makers often become anxious in the face of negative performance feedback (Xu, Zhou and Du, 2019). With the widening gap between performance and aspirations, the reputation and external legitimacy of firms are constantly reduced and threatened, resulting in the rationality of firm existence being questioned by stakeholders. Shareholders, investors, the media and public institutions often increase their attention and oversight as performance declines. Internal and external crises threaten the legitimacy and reputation of firms, forcing them to adjust their strategies to recover reputation loss and regain market confidence (Graffin, Boivie and

Carpenter, 2013). Firms tend to engage in R&D projects that change the current predicament in the short term to get rid of the operating pressure and reputation pressure caused by declining performance (Lv et al., 2019). Also, managers' reputation in the labour market is affected by declining performance. The decline in performance can be attributed to the failure of a firm due to the failure of its managers to develop or execute appropriate development strategies, and managers are also perceived as "strategic incompetence" (Lv et al., 2021). These strategic mistakes in business operation will have a serious adverse impact on managers' careers. In such case, managers are more inclined to adjust strategies (such as achieving R&D outputs in the short term) in order to eliminate the reputation of strategic incompetence (Graffin, Boivie and Carpenter, 2013; Baum and Dahlin, 2007). Therefore, when performance is below aspirations, firms pay more attention to the market effect and commercial value in R&D investment, and choose R&D projects that can quickly bring profits and change the current predicament to get rid of the operating pressure and reputation pressure brought by the decline in performance. At this time, firms are more willing to engage in R&D projects with high input-output rate, such as increasing application-oriented innovation with close, low cost and easy to obtain outputs to replace exploratory innovation with remote, high-cost and high failure rate (Lv et al., 2021), which is very attractive to firms and managers in urgent need of changing the status quo (Berchicci, 2013).

Second, the interrelationship between firms' participation in various strategic choices can be further understood from the perspective of resource constraints (Cheng et al., 2022). Abundant resources not only reduce resource constraints faced by enterprises and promote the implementation of strategic decisions, but also cushion the threat of failure to enterprise survival and enable enterprises to use resources more flexibly to carry out more experiments. In contrast, the decision-making errors of resource-rich firms will not have a substantial impact on them, and the marginal utility caused by the loss is relatively small. However, for resource-poor firms, they are very sensitive to the cost caused by decision-making errors. As the gap between performance below aspirations increases, resource constraints continue to intensify, limiting the resource input of R&D projects, and decision-makers will be less inclined to take risky behaviors in response to negative feedback (Lv et al., 2019). On the one hand, in the case of negative feedback, firms are less tolerant and more sensitive to R&D failures, and their recovery models are more inclined to choose deterministic innovations, because such innovation mode decreases the cost of trial-and-error, reduces the uncertainty of R&D output, and improves R&D input-output ratio. On the other hand, negative feedback changes the allocation mode of resources, makes more efficient use of limited resources, and improves R&D efficiency (Palmon and Yezegel, 2012). Thus, we propose hypothesis 1.

Hypothesis 1. Firms are more inclined to increase R&D efficiency as the performance falls below the aspiration level.

2.2. The moderating effect of institutional factors

The theory of modern institutional economics believes that institutions determine the basic factors of economic subject behavior. A large number of theoretical and empirical studies have shown that the institutional framework supporting the market is the key factor to promote economic development (Shirley, 2005). North (1990) states that institutions are a series of political, social and legal rules used to establish the basis of production, exchange and distribution, which constitute the incentive mechanism for political or economic transactions. Institutions have a significant impact on economic growth as they determine the incentive structure of core economic factors in the society, thus having a significant impact on investment activities (Acemoglu, Johnson and Robinson, 2005).

China has a vast territory, a huge population, and significant differences between different regions in terms of historical conditions, resource endowments and geographical transportation, leading to uneven institutional development in China. In particular, the gradient development strategy implemented by the central government in the 1970s has led to an increasing degree of institutional differentiation among regions, which is even more pronounced in the area of R&D. This is because institutional differences affect firms' transaction costs and expected benefits, which in turn influence their R&D strategy decisions (Levechenko, 2007; Peng et al., 2009). As a transition economy, China is characterized by incremental development and regional asynchrony, that is, the degree of local government intervention, IPR enforcement, and financial market development vary significantly across regions (Qiao, Shen, Zhang, and Chen, 2021; Yang, Yang and Sun, 2018). Therefore, we argue that when they consider investing in R&D in a region with a favorable institutional environment, firms are more inclined to improve R&D efficiency if negative feedback occurs.

First, the stronger the enforcement of the local IPR system, the more negative feedback can improve R&D efficiency. It has been shown that in regions with strong enforcement of laws and regulations, IPR regimes are effective in promoting science and technology innovation (Li and Zhang, 2007). On the contrary, in regions with weak institutional environment, laws and systems to protect intellectual property rights have been introduced, but the enforcement force is still relatively weak, resulting in more serious opportunistic behaviors, infringements of IPR, and unethical behaviors. In this institutional environment, firms are unable to obtain adequate protection from rules, perceivables, and standards, limiting the expected return of innovation activities (Li and Zhang, 2007). IPR regulations are designed to provide adequate legal protection against the risk of misappropriation for all firms without discriminating (Peng et al., 2017), however, the positive externalities and spillovers of R&D make it difficult for firms to safeguard their R&D outputs in areas with low enforcement (Levechenko, 2007). Strong IPR enforcement effectively restrains or reduces opportunism, knowledge theft and free-riding in the R&D process (Gao, Gao, Zhou and Huang, 2015; Shu, Zhou, Xiao and Gao, 2016), protects R&D outputs (Claessens and Leaven, 2003; Lin, Lin,and Song, 2010) and ensure the R&D income of firms (Chesbrough, 2006). Patent rights are important outputs of firms R&D inputs. The increase of patent rights value can significantly increase the exclusivity of innovative technology and obtain more monopoly profits. Previous research has addressed that stronger IPR enforcement leads to more patents and IPR infringement significantly inhibits firms' R&D activities (Albino-Pimentel, Dussauge and Nayal, 2022). In addition, strong IPR enforcement reduces the survival risk of firms. As mentioned earlier, strong IPR enforcement is conducive to ensuring R&D returns, and increased profits in turn improve the ex-ante incentives for R&D and promote the probability of R&D investment turning into R&D results. With the smooth transformation of R&D results and obtaining reasonable returns, the survival risk of firms is significantly reduced. Therefore, we expect strong IPR enforcement to help firms become more efficient when making R&D investments under negative feedback.

Second, the higher the level of development of local financial markets, the more negative feedback can improve R&D efficiency. In a well-developed market mechanism, the value of a firm is related to investment opportunities. However, financial frictions such as information asymmetry make firms often face higher external financing costs when investing, leading to different degrees of financing constraints. Compared with physical investment such as fixed assets, R&D investment has great heterogeneity, such as high risk, high adjustment cost, and incomplete exclusivity. As a result, compared with ordinary capital investment, firms face more severe financing constraints when engaging in R&D activities (Hsu, Tian and Xu, 2014; Brown, Martinsson and Petersen, 2012; Brown, Fazzari and Petersen, 2009), especially in the case of declining performance (Lv et al., 2019). In regions with highly developed financial markets, there are a large number of financial intermediaries, which mitigates the information asymmetry of R&D activities. Moreover, a competitive credit market improves the risk tolerance of financial intermediaries, increases the willingness of credit supply for R&D investment, and alleviates the overall financing constraints of firms by reducing the loan price (Ayyagari, Demirguc-Kunt and Maksimovic, 2011) and increasing the availability of loans (Love and Pería, 2014), thus forming a positive incentive effect on R&D activities of enterprises (Hsu et al., 2014). On the contrary, in areas with low financial market development, due to the lack of credit market competition, financial intermediaries have insufficient motivation to search for customers and screen information, as well as weak awareness of capital monitoring and risk management, leading to higher financing costs borne by enterprises and inhibition of R&D activities (Brown and Peterson, 2011). Thus, we suggest that a firm's R&D efficiency when performance falls below expectations will be more significantly depend more on the advantages of well-developed local financial markets.

Third, the lower the level of local government intervention, the more negative feedback can improve R&D efficiency. According to extant literature, R&D activities of firms are affected by government intervention through influencing the activity allocation of entrepreneurs. Baumol (1990) believes that the activities of entrepreneurs are divided into productive activities, unproductive activities and destructive activities, and how to allocate their time and energy depends on the institutional environment, as it determines the relative returns of the above activities and provides the corresponding incentive structure for entrepreneurs to make decisions. In the past several decades, China's market reform has made great achievements, and the institutional environment faced by entrepreneurs has also been greatly improved. However, it should not be ignored that, compared with developed market economy countries and regions, a large number of important production resources are still under the control of local governments, especially for local governments to the strength control of the factors such as land, capital and labor market, and even may be artificially lower the price of factors of production in pursuit of GDP growth (Yang et al., 2018). Low factor prices and strong government intervention undoubtedly provide strong incentives for firms to capture the rents caused by the distortion of production factors by building political relations and other ways. In a region with a higher degree of government intervention, entrepreneurs are more inclined to build political relations to obtain certain factor resources through rent-seeking behavior. Rent-seeking activities increase the operation and transaction costs of firms, expose firms to higher risks of R&D, and crowd out R&D investment funds (Chen, Li, Su, and Zheng, 2011). Moreover, if the rewards brought by rent-seeking activities are large enough, more entrepreneurial activities will be allocated in rent-seeking, and resources will be directly used for rent-seeking activities instead of R&D activities, resulting in a mismatch of entrepreneurial talents and reducing R&D efficiency. Recent studies have confirmed that entrepreneurs change incentive behavior through power rent-seeking, disrupting the balance among firms in the industry, and preventing firms from investing capital to improve R&D efficiency (Qiao et al., 2021).

In sum, we propose the following hypothesis.

Hypothesis 2. Compared with weak regional institutional environment, favorable regional institutional environment strengthens the promoting effect of negative feedback on R&D efficiency.

Hypothesis 2a. The higher the enforcement of the local IPR regime, the stronger the promotion effect of negative feedback on R&D efficiency.

Hypothesis 2b. The higher the development level of the local financial market, the stronger the promoting effect of negative feedback on R&D efficiency.

Hypothesis 2c. The lower the degree of local government intervention, the stronger the promoting effect of negative feedback on R&D efficiency.

3. Research Methodology

3.1. Data and sample

Our research uses the sample of all Chinese A-share listed companies from 2010 to 2019. Since Chinese listed companies began standardizing the disclosure of R&D expenditures in their annual reports in 2008, we start the sample in 2010 to allow for a two-year period with reliable R&D expenditure data to calculate R&D capital (Gao and Chou, 2015), as well as to take into account the impact of the financial crisis on performance and R&D activities.

The main data comes from the China Securities Market and Accounting Research (CSMAR) database, which is the largest and most comprehensive database of Listed Companies in China. The regional institutional environment index, intellectual property protection index, government intervention index and financial market development index are all derived from China Market Index database, which has been used by many scholars in studies related to Chinese institutions. The database is based on two sources: provincial statistics from statistical departments and other government departments, as well as data from sample surveys of enterprises across the country. The original data from different sources and different diameters were standardized according to the unified method, and the horizontal and longitudinal comparable indexes were formed.

Companies in finance and utility industries are excluded because they operate in highly regulated industries with different accounting rules than other industries (Burgstahler and Dichev, 1997). To eliminate the interference of extreme values, the main continuous variables were processed by winsorize at the upper and lower 1% levels. After removing the missing values, we finally obtained 3663 sample observations for 472 firms across 19 industries.

3.2. Variables

3.2.1. Dependent variable: R&D efficiency

The DEA model created by Charness et al. (1978), including the traditional CCR model and BCC model, is used to measure the degree to which an organization needs equal proportional improvement in input (output) when it reaches the production frontier. However, for the ineffective DEA, the gap between the current state and the strong effective target value does not take into account the influence of "slack" of factors, except for the part of equal proportion improvement, so its efficiency evaluation may be biased. The non-radial and non-angular Slacks-Based Measure (SBM) model proposed by Tone (2001) can directly deal with input excess and output insufficiency, which effectively solves the problem of the influence of "slack" factors on efficiency. However, there would be multiple effective units in the calculation process of SBM model, that is, the efficiency value of multiple decision making units(DMUs) is 1. Therefore, Tone (2002) introduced the super-SBM model on the basis of the SBM model to make up for the inability of the SBM model to distinguish effective DMUs. The effective DMUs are first removed from the production possibility set and their distance to the production frontier is measured, which can not only sort the invalid DMUs but also distinguish the effective DMUs, as shown in the following equation.

Suppose there are n DMUs associated with m inputs and s outputs. X_{ij} represents the ith input of DMU, while Y_{rj} represents the rth output of DMU, assuming all data are positive, then the set P of all production possibilities is expressed as

$$P = \left\{ (x_1, \dots, x_m, y_1, \dots, y_s) \mid x_i \geq \sum_{j=1}^{n} \lambda_j x_{ij}, i = 1, \dots, m, y_r \leq \sum_{j=1}^{n} \lambda_j y_{rj}, r = 1, \dots s \right\} \tag{1}$$

And the following super-SBM model to evaluate the efficiency of DMU k.

$$\begin{gathered} min\theta = \frac{1 + \frac{1}{m} \sum_{i=1}^{m} s_i^- / x_{ik}}{1 - \frac{1}{s} \sum_{r=1}^{s} s_r^+ / y_{rk}} \\ s.t. \sum_{j=1, j \neq k} x_{ij} \lambda_j - s_i^- \leq x_{ik} (i = 1,2, \dots, m) \\ \sum_{j=1, j \neq k}^{n} y_{rj} \lambda_j + s_r^+ \geq y_k (r = 1,2, \dots, s) \\ \lambda \geq 0, j = 1,2, \dots, n (j \neq k), s_i^- \geq 0, s_r^+ \geq 0 \end{gathered} \tag{2}$$

Where, x and y represent the variables of input and output respectively, m and s represent the number of factors for inputs and outputs respectively. The vectors S^-_i and S^+_r stand for excess input and insufficient output of this expression respectively, called slacks, and λ_j is the weight vector. In the calculation of R&D efficiency, R&D output (y) is measured by the number of patent applications, and R&D input (x) is measured by the total amount and intensity of R&D investment. In the super-SBM model constructed in this paper, λ_j is a non-fixed value that is automatically obtained from input and output data in the calculation of R&D efficiency. The problems of excess input and insufficient output can also be directly dealt with in the process of calculating R&D efficiency using super-SBM model, which effectively solves the problem of the influence of slack factor on efficiency. Thus, in the calculation of R&D efficiency, the R&D efficiency of an enterprise can be directly calculated through the super-SBM command in the case of obtaining input and output variables.

3.2.2. Independent variables

1. Negative Feedback

Following earlier studies (Greve, 2003; Lucas et al., 2018; Lv et al., 2019), we calculate two different aspiration levels based on return on assets (ROA): historical aspiration level and social aspiration level. The former derived from the company's historical ROA; the latter derived from the median ROA of competing companies in the industry. The historical aspiration is expressed as the exponentially weighted moving average of company's past performance, as shown in equation 3.

$$HAP_{i,t} = (1 - \alpha_1)P_{i,t-1} + \alpha_1 HAP_{i,t-1} \tag{3}$$

$HAP_{i,t}$ denotes the historical aspirations of company i at time t-1, and $P_{i,t-1}$ denotes the actual performance of company i at time t-1. α_1 is an adjustment parameter, that is, a higher α_1 means more weight is placed on the most recent performance rather than on the farther performance. The weight α_1 is determined by searching all possible values (in increments of 0.1) and adopting a combination that provides the highest model log-likelihood in a baseline model containing only control variables (Lv et al., 2019). This process produces a value of $\alpha_1 = 0.4$. In this paper, a dummy variable I_1 is set to be the indicator variable of the underperforming firm, equal to 1 if performance is lower than historical aspirations, and 0 otherwise. Therefore, performance below historical expectations is defined as $I_1 \times (P_{i,t-1} - HAP_{i,t-1})$.

Similarly, we construct social aspiration level, as shown in equation 4.

$$SAP_{i,t} = (1 - \alpha_1)IP_{i,t-1} + \alpha_1 SAP_{i,t-1} \tag{4}$$

Also, we try different weights from 0 to 1 by increasing the weight by 0.1 each time. As Lv et al. (2019), we only report results based on $\alpha 1 = 0.4$, which it gives highest model log-likelihood. $IP_{i,t-1}$ is the median ROA of all other companies in the same industry at the three-digit SIC level during the year (Gentry and Shen, 2013; Lv et al, 2019). We set a dummy variable I_2, which is equal to 1 if performance is lower than social aspirations, and 0 otherwise. Thus, performance below social aspirations is defined as $I_2 \times (IP_{i,t-1} - SAP_{i,t-1})$.

2. Institutional Environment

The regional institutional environment index, intellectual property protection index, government intervention index and financial market development index are all derived from the Annual China Provincial Market Index database. Among them, the regional *institutional environment index* is compiled by principal factor analysis based on a large number of statistical and survey data, covering the relationship between government and market, product market development, factor market development, intermediary organization development and law. The larger the index, the better the regional system.

The *IPR enforcement* Index is compiled by taking into account the protection of producers' legitimate rights and interests and intellectual property protection. The larger the index is, the stronger the enforcement of regional laws and regulations is. The *financial market development* index is a comprehensive consideration of financial industry competition and the marketization of credit capital allocation. The higher the index is, the higher the degree of regional financial market development is. The *government intervention* index is measured by investigating the proportion of the time that main managers spend dealing with government departments and personnel in their working time. A small index means that main managers need to spend more time dealing with the government, indicating a high degree of government intervention in enterprises.

3.2.3. Control variables

We control some control variables that explain differences in size, debt ratios and age in our samples (Lv et al., 2019). *Firm Size* is measured by the logarithm of the total number of employees at the end of the year while *Debt Ratio* is measured by the ratio of liabilities to assets. *Firm Age* is measured by the number of years since listed. According to previous literature (Chen, Xie and Essen, 2021), we include the Herfindah-Hirschmann index (*HHI*) for each industry to control industry competition. *Slack* is also controlled, as firms with more slack resources invest more aggressively in R&D. We measure owner's equity to debt ratios as available slack. Also, according to previous literature (Shipilov, Greve, and Rowley, 2019; Lv et al., 2021), we include some corporate governance characteristics to control the impact of the heterogeneity of the senior management team. *CEO Duality*, a dummy variable, is 1 if the chairman and CEO are the same person, and 0 otherwise. *Board Size* is measured as the logarithm of the number of board members, *Share Centralization (Shrcr)* is measured by the square sum of the shares held by the top five major shareholders, and *Independent Director (Indepdirector)* is measured by the proportion of independent directors.

A large number of literatures have proved that government subsidies have a significant positive impact on R&D efficiency (Kang and Park, 2012; Choi, Lee and Williams, 2011), because government subsidies promote the improvement of R&D efficiency through financial allocation, interest subsidy, tax credit. *Government subsidies(Subsidy)* are controlled and measured as the logarithm of the total amount of government subsidies. In addtion, we include *year, industry* and *province* to control the influence of time variation, industry and region on R&D efficiency.

3.3. Models

To alleviate potential endogeneity issues, according to previous documents (Chen and Miller, 2007; Lv et al.,2019), the independent variable lags behind the dependent variable by one year. Also, we include industry fixed effects, year fixed effects, and province fixed effects to control time fluctuations, industry impacts, and regional impacts on firm R&D efficiency, and adopt robust standard errors to control for heteroscedasticity of panel data. Combining our issues, the following equation is formulated:

$$\begin{aligned} Rde_{i,t} = \beta_0 + \beta_1 \lfloor I_1 \times (P_{i,t-1} - HAP_{i,t-1}) \rfloor + \beta_2 Debtratio_{i,t} + \beta_3 Firmsize_{i,t} + \beta_4 Firmage_{i,t} \\ + \beta_5 Slack_{i,t} + \beta_6 HHI_{i,t} + \beta_7 Shrcr_{i,t} + \beta_8 CEOduality_{i,t} + \beta_9 Boardsize_{i,t} \\ + \beta_{10} Indepdirector_{i,t} + \beta_{11} Subsidy_{i,t} + \sum Province + \sum Year + \sum Ind + \varepsilon_{i,t} \end{aligned} \tag{5}$$

$$\begin{aligned} Rde_{i,t} = \beta_0 + \beta_1 \lfloor I_2 \times (IP_{i,t-1} - SAP_{i,t-1}) \rfloor + \beta_2 Debtratio_{i,t} + \beta_3 Firmsize_{i,t} + \beta_4 Firmage_{i,t} \\ + \beta_5 Slack_{i,t} + \beta_6 HHI_{i,t} + \beta_7 Shrcr_{i,t} + \beta_8 CEOduality_{i,t} + \beta_9 Boardsize_{i,t} \\ + \beta_{10} Indepdirector_{i,t} + \beta_{11} Subsidy_{i,t} + \sum Province + \sum Year + \sum Ind + \varepsilon_{i,t} \end{aligned} \tag{6}$$

We examine the relationship between performance below historical aspirations and R&D efficiency, and between performance below social aspirations and R&D efficiency, respectively. If β_1 is significantly negative, it indicates that performance below aspirations is beneficial to improve firms' R&D input-output ratio, while if β_1 is significantly positive, it indicates that performance below aspirations inhibits R&D input-output ratio.

4. Empirical Results

4.1. Descriptive statistics

Table 1 presents the descriptive statistics of 3663 observations for major variables. The mean value of R&D efficiency is 0.028, indicating that the R&D efficiency of enterprises in the sample is low on the whole. The mean values of historical negative feedback and social negative feedback are 0.016 and 0.021 respectively, indicating that the average gap between the actual performance of an enterprise below the historical expectation level is 0.016, while the average gap between the performance below the industry expectation level is 0.021. Combining these data shows that the pressure on decision-makers to raise performance above social aspirations is greater than the pressure to raise performance above historical aspirations. The average (median) of institutional environment index, IPR enforcement index, financial market development index and government intervention index are 8.532 (9.120), 11.35 (12.15), 7.826 (7.260) and 7.006 (7.130), and the standard deviations are 1.733, 5.342, 2.858 and 1.432, respectively, indicating that there are great differences in institutional indexes in different regions.

Table 1. Descriptive statistics.

Variables	N	mean	sd	min	p25	p50	p75	max
R&D efficiency	3663	0.028	0.059	0.002	0.007	0.011	0.023	0.446
I_1 x ($P_{i,t-1}$ - $HAP_{i,t-1}$)	3663	-0.016	0.031	-0.236	-0.021	-0.001	0	0
I_2 x ($IP_{i,t-1}$ - $SAP_{i,t-1}$)	3663	-0.021	0.054	-2.276	-0.030	-0.006	0	0
Institutional Environment	3663	8.532	1.733	-1.420	7.330	9.120	9.860	11.40
IPR Enforcement	3663	11.35	5.342	0.000	6.720	12.15	15.56	24.33
Financial Market Development	3663	7.826	2.858	-1.210	5.820	7.260	9.080	15.87
Government Intervention	3663	7.006	1.432	-14.29	6.150	7.130	8.060	9.220
Debtratio	3663	0.400	0.194	0.00906	0.246	0.400	0.536	0.955
Firmsize	3663	7.811	1.152	4.078	7.029	7.732	8.508	12.14
Firmage	3663	12.87	6.081	2	8	11	18	29
Slack	3663	2.827	4.543	0.0471	0.865	1.500	3.063	15.780
HHI	3663	0.258	0.248	0.0142	0.083	0.196	0.267	1
Shrcr	3663	0.153	0.108	0.00142	0.070	0.125	0.212	0.794
CEOduality	3663	0.287	0.452	0	0	0	1	1
Boardsize	3663	2.252	0.189	1.792	2.079	2.303	2.303	2.890
Indepdirector	3663	0.373	0.053	0.250	0.333	0.333	0.429	0.714
Subsidy	3663	16.52	1.464	8.923	15.64	16.45	17.37	21.79

4.2. Baseline Analysis

Table 2 presents the regression results of hypothesis 1. In Model 1, we only incorporate firm-, governance-, and industry characteristics in the regression. We can see that debt ratio has a significant positive impact on R&D efficiency, suggesting that firms with high debt ratio are more motivated to improve R&D outputs. The significant positive relationship between firm size and R&D efficiency indicates that large firms have more capability to improve R&D outputs than small ones. Existing literature shows that firm age has a negative impact on R&D investment (Lu and Wong, 2019), however, we find that firm age has a significant positive impact on R&D efficiency, as compared with young firms, older firms are more perfect in governance and more experienced in technological innovation, which may reduce the cost loss caused by the experimental stage. Government subsidies have a significant positive impact on R&D efficiency, indicating that government subsidies are more conducive to improving R&D efficiency.

Table 2. Regression results of negative feedback and R&D input-output ratio.

	Dependent variable =R&D efficiency		
Variables	(1)	(2)	(3)
$I_1 x (P_{i,t-1} - HAP_{i,t-1})$		-0.0696**	
		(-2.3599)	
$I_2 x (IP_{i,t-1} - SAP_{i,t-1})$			-0.1335***
			(-7.7438)
Debtratio	0.0164**	0.0160**	0.0109
	(2.4162)	(2.3553)	(1.6082)
Firmsize	0.0034***	0.0035***	0.0042***
	(2.7277)	(2.8105)	(3.3891)
Firmage	0.0008***	0.0008***	0.0007***
	(4.0945)	(4.0203)	(3.8858)
Slack	0.0003	0.0003	0.0002
	(1.1527)	(1.1058)	(0.8857)
HHI	0.0010	0.0012	0.0017
	(0.2268)	(0.2763)	(0.3920)
Shrcr	0.0055	0.0057	0.0064
	(0.5790)	(0.6090)	(0.6787)
CEOduality	-0.0012	-0.0011	-0.0007
	(-0.5711)	(-0.4958)	(-0.3289)
Boardsize	-0.0024	-0.0019	-0.0020
	(-0.3397)	(-0.2668)	(-0.2853)
Indepdirector	0.0153	0.0153	0.0115
	(0.7160)	(0.7149)	(0.5407)
Subsidy	0.0027***	0.0027***	0.0032***
	(3.2520)	(3.2995)	(3.8803)
Constant	-0.1043***	-0.1094***	-0.1155***
	(-3.8925)	(-4.0720)	(-4.3401)
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
Adjusted R^2	0.1380	0.1391	0.1519
N	3663	3663	3663

*Note: We estimate the model using ordinary least squares (OLS) and all variable definitions are the same as above. Z/T statistics are reported in parentheses. *, ** and ** were significant at 10%, 5% and 1% levels, respectively.*

Model 2 shows the results of historical negative feedback and R&D efficiency. The results show that the coefficient of historical negative feedback is -0.0696, and it has a significant negative correlation with R&D efficiency at the level of 5%, indicating that R&D efficiency of firms increases as actual performance falls below the historical aspiration level. The economic significance of historical negative feedback on R&D efficiency is further calculated, that is, R&D efficiency increases 0.0696% for every 1% decrease of historical negative feedback, and R&D efficiency increases 0.216% on average for every unit standard deviation decrease of historical negative feedback, which is about 7.706% (0.0696×0.031/0.028) of the mean R&D efficiency. The above results have statistical and economic significance.

Mode 3 shows the test results of social negative feedback and R&D efficiency. The results show that the coefficient of social negative feedback is -0.1335, and it is significantly negatively correlated with R&D efficiency at 1% level, indicating that R&D efficiency increases with performance lower than social aspirations. Similarly, R&D

efficiency increases by 0.1335% for every 1% decrease in negative social feedback, and R&D efficiency increases by 0.721% on average for every unit standard deviation decrease of negative social feedback, which is about 25.75% of the average R&D efficiency (0.1335×0.054/0.028). The above results indicate that R&D efficiency of firms increases as performance falls below the aspiration level, which strongly supports hypothesis 1.

Recent studies have shown that in the case of negative feedback, firms will change the direction or reduce the intensity of R&D, shifting more resources from R&D to other activities they consider more important to overall performance, such as marketing and sales, operations or after-sales service support (Saemundsson et al. 2022). However, our findings suggest another possibility. When performance is below expectations, firms may respond to risks by engaging in R&D projects that are close, low-cost and easy to obtain outputs (Lv et al., 2021). These R&D outputs alleviate the doubts of external stakeholders and to some extent recover the reputation loss of firms and managers. They also become alternative means for firms to shorten product life cycle and speed up product renewal, and help firms regain market confidence (Graffin, Boivie and Carpenter, 2013).

4.3. Testing for potential regulatory mechanisms

Having verified the impact of negative feedback on R&D efficiency, we further explorer how the institutional environment moderates the relationship between them. According to the median of institutional environment value, we divide institutional environment into two groups. If it is greater than or equal to the median, Inst_e=1, and it is 0 otherwise. As shown in Table 3, The coefficients of historical negative feedback (coefficient is -0.1058, P<0.01) and social negative feedback (coefficient is -0.1400, P<0.01) are significantly negative for the models with Inst_e=1, but not significant for the models with Inst_e=0 (coefficient is 0.0400, P>0.1, coefficient is -0.0416, p> 0.1), indicating that the perfect institutional environment strengthens the impact of negative feedback on R&D efficiency and supports hypothesis 2.

Moreover, Chi-square test is used to test whether there are differences in the impact of negative feedback on R&D efficiency after grouping, and the results show that the coefficients between groups have significant differences (Chi-square=6.64, p<0.01; Chi-square=3.68, p<0.1). The above results show that in the case of negative feedback, perfect institutional environment contributes to the improvement of R&D efficiency, while poor institutional environment increases the acquisition cost of R&D resources due to the lack of sound property rights protection, poor factor flow and rent-seeking behavior, thus weakens the impact of negative feedback on R&D efficiency.

Table 3. Testing the regulatory mechanism of institutional environment.

Variables	(1) Historical Inst_e=1	(2) Historical Inst_e=0	(3) Social Inst_e=1	(4) Social Inst_e=0
I_1 x ($P_{i,t-1}$ - $HAP_{i,t-1}$)	-0.1058***	0.0400		
	(-3.0725)	(0.7486)		
I_2 x ($IP_{i,t-1}$ - $SAP_{i,t-1}$)			-0.1400***	-0.0416
			(-8.0362)	(-0.8822)
Debtratio	0.0184**	0.0148	0.0135*	0.0122
	(2.3170)	(1.1343)	(1.7147)	(0.9233)
Firmsize	0.0012	0.0058***	0.0020	0.0062***
	(0.8056)	(2.6341)	(1.3311)	(2.8263)
Firmage	0.0007***	0.0008**	0.0007***	0.0008**
	(3.1066)	(2.4844)	(2.9886)	(2.3724)
Slack	0.0004	0.0001	0.0003	0.0001
	(1.4779)	(0.2195)	(1.2680)	(0.1716)
HHI	-0.0039	0.0118	-0.0030	0.0117
	(-0.7926)	(1.5178)	(-0.6221)	(1.5117)

Shrcr	0.0223*	-0.0155	0.0236**	-0.0162
	(1.8946)	(-1.0038)	(2.0304)	(-1.0513)
CEOduality	-0.0025	0.0033	-0.0018	0.0032
	(-0.9850)	(0.8532)	(-0.7405)	(0.8291)
Boardsize	0.0006	-0.0068	-0.0012	-0.0059
	(0.0684)	(-0.5817)	(-0.1340)	(-0.5106)
Indepdirector	0.0091	0.0243	0.0027	0.0254
	(0.3475)	(0.6789)	(0.1035)	(0.7099)
Subsidy	0.0030***	0.0022	0.0037***	0.0022
	(2.9490)	(1.6444)	(3.6712)	(1.6334)
Constant	0.0002	0.0000	0.0002	0.0000
	(0.9324)	(0.1105)	(0.9245)	(0.0454)
Province	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Adjusted R^2	0.1796	0.1640	0.2005	0.1641
N	2180	1483	2180	1483
Coefficient test	6.64*** (0.010)		3.68*(0.0551)	

*Note: We estimate the model using ordinary least squares (OLS) and all variable definitions are the same as above. Z/T statistics are reported in parentheses. *, ** and ** were significant at 10%, 5% and 1% levels, respectively.*

We further test the moderating effect of institutional environment characteristics such as IPR enforcement, financial marketization and government intervention on R&D efficiency under negative feedback, and the results are shown in Table 4. We first consider the moderating effect of IPR enforcement on R&D efficiency. In order to better identify the impact of IPR enforcement differences on the above relationship, we divided the IPR enforcement index into two groups with the median as the boundary. If the index of the firm location is greater than or equal to the median, IPR_e=1; otherwise, it is 0. As shown in Models 1-4, in the models with IPR_e=1, the coefficients of historical negative feedback and social negative feedback are significantly negative (coefficient =-0.1092, P< 0.01; Coefficient =-0.1515, P<0.01), while in the models with IPR_e=0, the coefficients of historical negative feedback and social negative feedback are not significant, indicating that IPR enforcement strengthens the impact of negative feedback on R&D efficiency, which supports hypothesis 2a. Chi-square test shows significant differences in coefficients between groups (Chi-square=2.86, p<0.1; Chi-square=3.6, p<0.1). Our results show that in regions with strong enforcement of laws and regulations, IPR effectively constrains or reduces opportunism, knowledge theft, and free-riding in R&D process, ensures R&D revenue, reduces survival risk, and further strengthens the impact of negative feedback on R&D efficiency. Conversely, in regions with poor enforcement of laws and regulations, issues such as opportunistic behavior, intellectual property infringement, and legal but unethical behavior prevent firms from feeling adequate protection from rules, perceived and standards, limiting the expected return of innovation activities and inhibiting the promotion of negative feedback on R&D efficiency.

We explore the moderating effect of differences in financial market development on R&D efficiency under negative feedback. We take the median of the financial market development index of the location of the firm as the boundary. If it is greater than or equal to the median, Fian_d=1; otherwise, it is 0. As shown in Models 5-8, compared with the Fian_d=0 mode, the coefficients of historical negative feedback and social negative feedback are both significantly negative in the models with Fian_d=1 (Coefficient =-0.1502, P<0.01; Coefficient =-0.1703, P>0.01), indicating that the degree of financial market development strengthens the impact of negative feedback on R&D efficiency, which supports hypothesis 2b. Chi-square test results show significant differences in coefficients between groups (Chi-square=3.79, p<0.1; Chi-square=14.94, p<0.01). Our results suggest that large amounts of financial intermediation can mitigate information asymmetry in firm R&D activities in regions with developed financial markets. The competitive credit market improves the risk tolerance of financial intermediaries, increases the willingness of credit supply for R&D investment, alleviates the overall financing constraint of enterprises by reducing the loan price and increasing the availability of loans, and further strengthens the positive incentive effect of negative feedback on R&D efficiency.

Finally, we examine the impact of government intervention differences on R&D efficiency in the case of negative feedback. Similarly, with the median as the boundary, we divide the index into two groups. If the value is greater than or equal to the median, Gov_inter=1; otherwise, it is 0. As shown in Models 9-12, the coefficients of historical negative feedback and social negative feedback are significantly negative in the model with Gov_inter=1 (Coefficient =-0.1377, P<0.01; Coefficient =-0.1453, P<0.01), but not significant in the model with Gov_inter=0, indicating that the government's intervention on firms weakens the impact of negative feedback on R&D efficiency, which supports hypothesis 2c. The chi-square test results show that there are significant differences in the coefficients after grouping. The above results indicate that firms tend to obtain key resources through rent-seeking in areas with high government intervention. Rent-seeking activities not only squeeze the investment of R&D funds and cause the mismatch of entrepreneurial talents, but also change the incentive behavior, destroy the balance among firms in the industry, hinder firms from investing a large amount of money to improve R&D efficiency, and finally weaken the promoting effect of negative feedback on R&D efficiency.

Table 4. Testing the regulatory mechanism of institutional factors.

	IPR Enforcement				Financial Market Development				Degree of Government Intervention			
	IPR_e=1	IPR_e=0	IPR_e=1	IPR_e=0	Fian_d=1	Fian_d=0	Fian_d=1	Fian_d=0	Gov_inter=1	Gov_inter=0	Gov_inter=1	Gov_inter=0
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$I_1 x (P_{i,t-1} - HAP_{i,t-1})$	-0.1092***	-0.0231			-0.1502***	0.0091			-0.1377***	0.0281		
	(-2.6377)	(-0.5415)			(-3.1533)	(0.2496)			(-4.0029)	(0.6097)		
$I_2 x (IP_{i,t-1} - SAP_{i,t-1})$			-0.1515***	-0.0527			-0.1703***	-0.0132			-0.1453***	-0.0408
			(-7.8170)	(-1.3722)			(-7.9335)	(-0.3995)			(-9.2168)	(-1.0236)
Debtratio	0.0194**	0.0093	0.0135	0.0073	0.0195*	0.0124	0.0132	0.0118	0.0292***	0.0055	0.0246***	0.0033
	(2.1474)	(0.8224)	(1.5165)	(0.6443)	(1.8868)	(1.3780)	(1.2857)	(1.2979)	(3.6199)	(0.5203)	(3.1057)	(0.3078)
Firmsize	0.0034**	0.0040**	0.0041**	0.0044**	0.0000	0.0061***	0.0006	0.0062***	0.0002	0.0065***	0.0012	0.0069***
	(1.9788)	(2.0918)	(2.4541)	(2.2548)	(0.0207)	(3.5286)	(0.3046)	(3.5663)	(0.1144)	(3.3092)	(0.8002)	(3.4817)
Firmage	0.0008***	0.0006**	0.0008***	0.0006**	0.0012***	0.0003	0.0012***	0.0003	0.0008***	0.0009***	0.0007***	0.0009***
	(2.8618)	(2.4383)	(2.7777)	(2.3587)	(4.3440)	(1.1717)	(4.3307)	(1.1330)	(3.5986)	(3.0702)	(3.4115)	(3.0063)
Slack	0.0005*	-0.0002	0.0004	-0.0002	0.0004	-0.0000	0.0002	-0.0000	0.0005*	0.0000	0.0004	0.0000
	(1.7550)	(-0.4069)	(1.5284)	(-0.4204)	(0.9963)	(-0.0477)	(0.6506)	(-0.0620)	(1.7086)	(0.1040)	(1.5885)	(0.0518)
HHI	-0.0029	0.0062	-0.0020	0.0062	-0.0001	0.0070	0.0006	0.0071	0.0023	0.0023	0.0035	0.0024
	(-0.5159)	(0.9457)	(-0.3658)	(0.9365)	(-0.0094)	(1.2415)	(0.0985)	(1.2521)	(0.4807)	(0.3392)	(0.7450)	(0.3499)
Shrcr	0.0236*	-0.0155	0.0252*	-0.0158	0.0351**	-0.0146	0.0364**	-0.0147	0.0261**	-0.0067	0.0272**	-0.0070
	(1.7382)	(-1.1507)	(1.8859)	(-1.1710)	(2.2065)	(-1.2774)	(2.3265)	(-1.2856)	(2.2789)	(-0.4727)	(2.4256)	(-0.4933)
CEOduality	-0.0013	0.0007	-0.0004	0.0007	-0.0062*	0.0045	-0.0053	0.0045	-0.0012	-0.0009	-0.0006	-0.0008
	(-0.4509)	(0.2118)	(-0.1558)	(0.2058)	(-1.8407)	(1.6220)	(-1.6116)	(1.6411)	(-0.4968)	(-0.2625)	(-0.2720)	(-0.2426)
Boardsize	0.0006	-0.0056	-0.0017	-0.0054	0.0025	-0.0065	0.0005	-0.0063	-0.0168*	-0.0037	-0.0195**	-0.0033
	(0.0520)	(-0.5659)	(-0.1548)	(-0.5466)	(0.2283)	(-0.6987)	(0.0436)	(-0.6722)	(-1.8093)	(-0.3530)	(-2.1442)	(-0.3149)
Indepdirector	-0.0060	0.0370	-0.0144	0.0370	-0.0372	0.0640**	-0.0469	0.0639**	-0.0133	0.0157	-0.0194	0.0151
	(-0.1904)	(1.2571)	(-0.4629)	(1.2590)	(-1.0840)	(2.4029)	(-1.3864)	(2.4003)	(-0.5072)	(0.4874)	(-0.7539)	(0.4686)
Subsidy	0.0045***	0.0002	0.0053***	0.0003	0.0060***	-0.0004	0.0070***	-0.0004	0.0015	0.0033***	0.0024**	0.0033***
	(4.0103)	(0.1814)	(4.7285)	(0.2255)	(4.6980)	(-0.3908)	(5.5224)	(-0.3881)	(1.5307)	(2.6289)	(2.4831)	(2.6545)
Constant	-0.1077**	-0.0702*	-0.1228***	-0.0719**	-0.1130**	-0.0773**	-0.1190**	-0.0791**	0.0067	-0.1306***	-0.0092	-0.1341***
	(-2.2619)	(-1.9179)	(-2.6179)	(-1.9708)	(-1.9919)	(-2.3147)	(-2.1304)	(-2.3720)	(0.1694)	(-3.3052)	(-0.2361)	(-3.4025)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.1408	0.1864	0.1649	0.1872	0.1578	0.1726	0.1827	0.1726	0.2167	0.1632	0.2477	0.1635
N	1942	1721	1942	1721	1806	1857	1806	1857	1731	1932	1731	1932
Coefficient test	2.86*(0.0905)		3.60*(0.0576)		3.79*(0.0517)		14.94***(0.0001)		4.69**(0.0304)		5.21**(0.0224)	

*Note: We estimate the model using ordinary least squares (OLS) and all variable definitions are the same as above. Z/T statistics are reported in parentheses. *, ** and ** were significant at 10%, 5% and 1% levels, respectively.*

4.4. Robustness Tests

Robustness tests are as follows: First, various performance measures, such as return on assets (ROA), return on sales (ROS) and return on equity (ROE), may be related to managers' expectations when evaluating performance. ROE is influenced by the relative combination of the company's equity and liabilities (Iyer and Miller, 2008), so we choose ROS as a robustness test of performance proxy and conduct prior regressions again. Second, considering the large R&D expenditure of enterprises in manufacturing and IT industries, we select enterprises in the above two industries as samples and conduct the above tests again. Robustness tests show that the results are robust and support conclusions consistent with those discussed previously. For brevity, we present these results in Appendix.

5. Conclusion

The aim of this study is to examine the impact of performance negative feedback on R&D efficiency. Using the sample of all Chinese A-share listed companies from 2010 to 2019, we find that performance below aspirations may prompts firms to pay more attention to the R&D projects with high R&D efficiency, because negative feedback forces firms to engage in R&D projects that quickly bring market effect and commercial value, so as to get rid of the operating pressure, reputation pressure and resource constraints brought by the decline in performance. This effect may be influenced by institutional factors. In the case of negative feedback, compared with the weak regional institutional environment, the perfect regional institutional environment is more conducive to the improvement of R&D efficiency. Specifically, the higher the degree of IPR enforcement and financial market development and the lower the government intervention, the more inclined firms are to improve R&D efficiency when the performance is lower than the aspiration level.

Our study has some implications for policy makers. In order to encourage enterprises to improve their R&D efficiency and innovation capability, it is necessary to formulate clearly established and properly enforced laws and institutions to protect intellectual property rights in order to ensure that enterprises can reap the benefits of R&D activities. In addition, one of the priorities of government policies to support innovation is to minimize intervention in factor markets to reduce the rent-seeking motivation of firms. Finally, it is necessary to further enhance the marketization level of the financial industry, encourage financial innovation and relax financial regulation, so as to alleviate the financing constraints faced by enterprises' R&D activities.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Appendix

This Appendix includes tables related to the results of our data robustness analysis. The tables are presented in the following order:

1) Robust regression of ROS as a performance proxy: baseline regression results.

2) Robust regression of ROS as a performance proxy: regression results for regulatory mechanisms of institutional environment.

3) Robust regression of ROS as a performance proxy: regression results for regulatory mechanisms of institutional factors.

4) Robust regression with varying samples: Baseline regression results.

5) Robust regression with varying samples: regression results for regulatory mechanisms of institutional environment.

6) Robust regression with varying samples: regression results for regulatory mechanisms of institutional factors.

Table A1. Robust regression of ROS as a performance proxy: baseline regression results.

	Dependent variable =R&D efficiency		
Variables	(1)	(2)	(3)
$I_1 x (P_{i,t-1} - HAP_{i,t-1})$ros		-0.0465***	
		(-3.9795)	
$I_2 x (IP_{i,t-1} - SAP_{i,t-1})$ros			-0.0418***
			(-4.5039)
Debtratio	0.0164**	0.0154**	0.0120*
	(2.4162)	(2.2787)	(1.7473)
Firmsize	0.0034***	0.0037***	0.0040***
	(2.7277)	(2.9977)	(3.1567)
Firmage	0.0008***	0.0007***	0.0008***
	(4.0945)	(3.9611)	(4.0350)
Slack	0.0003	0.0002	0.0003
	(1.1527)	(0.9856)	(1.0996)
HHI	0.0010	0.0015	0.0012
	(0.2268)	(0.3487)	(0.2803)
Shrcr	0.0055	0.0067	0.0060
	(0.5790)	(0.7110)	(0.6349)
CEOduality	-0.0012	-0.0009	-0.0008
	(-0.5711)	(-0.4100)	(-0.3563)
Boardsize	-0.0024	-0.0011	-0.0016
	(-0.3397)	(-0.1486)	(-0.2303)
Indepdirector	0.0153	0.0147	0.0145
	(0.7160)	(0.6871)	(0.6786)
Subsidy	0.0027***	0.0027***	0.0028***
	(3.2520)	(3.3579)	(3.4717)
Constant	-0.1043***	-0.1119***	-0.1111***
	(-3.8925)	(-4.1767)	(-4.1526)
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
Adjusted R^2	0.1380	0.1415	0.1426
N	3663	3663	3663

*Note: ROS is used as a performance proxy to calculate historical negative feedback and social negative feedback, ordinary least squares (OLS) is used to estimate the model, and all variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

Table A2. Robust regression of ROS as a performance proxy: regression results for regulatory mechanisms of institutional environment.

Variables	(1) Historical Inst_e=1	(2) Historical Inst_e=0	(3) Social Inst_e=1	(4) Social Inst_e=0
$I_1 x (P_{i,t-1} - HAP_{i,t-1})$ros	-0.0742***	-0.0076		
	(-5.1829)	(-0.3624)		
$I_2 x (IP_{i,t-1} - SAP_{i,t-1})$ros			-0.0749***	-0.0134
			(-5.8192)	(-0.9439)
Debtratio	0.0151*	0.0125	0.0097	0.0110
	(1.8773)	(0.9619)	(1.2022)	(0.8426)

Firmsize	0.0036**	0.0052**	0.0040***	0.0054**
	(2.4542)	(2.4598)	(2.7708)	(2.5253)
Firmage	0.0009***	0.0009***	0.0009***	0.0009***
	(4.1023)	(2.6548)	(4.2976)	(2.6467)
Slack	0.0001	0.0000	0.0002	0.0000
	(0.5017)	(0.0705)	(0.6741)	(0.0644)
HHI	-0.0046	0.0110	-0.0043	0.0108
	(-0.8878)	(1.3945)	(-0.8376)	(1.3658)
Shrcr	0.0287**	-0.0047	0.0283**	-0.0047
	(2.4460)	(-0.3126)	(2.4240)	(-0.3155)
CEOduality	-0.0002	0.0021	0.0006	0.0020
	(-0.0622)	(0.5220)	(0.2280)	(0.5118)
Boardsize	0.0017	-0.0166	-0.0004	-0.0164
	(0.1872)	(-1.4712)	(-0.0475)	(-1.4571)
Indepdirector	-0.0041	0.0237	-0.0093	0.0243
	(-0.1550)	(0.6634)	(-0.3532)	(0.6797)
Subsidy	0.0019*	0.0029**	0.0021**	0.0029**
	(1.8654)	(2.1601)	(2.0286)	(2.1793)
Constant	-0.0517	-0.0828**	-0.0536	-0.0839**
	(-1.4121)	(-1.9995)	(-1.4661)	(-2.0282)
Province	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Adjusted R^2	0.0922	0.0992	0.0952	0.0997
N	2180	1483	2180	1483
Coefficient test	3.33*(0.0680)		2.91*(0.0879)	

*Note: ROS is used as a performance proxy to calculate historical negative feedback and social negative feedback, ordinary least squares (OLS) is used to estimate the model, and all variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

Table A3. Robust regression of ROS as a performance proxy: regression results for regulatory mechanisms of institutional factors.

	IPR Enforcement				Financial Market Development				Degree of Government Intervention			
	IPR_e=1	IPR_e=0	IPR_e=1	IPR_e=0	Fian_d=1	Fian_d=0	Fian_d=1	Fian_d=0	Gov_inter=1	Gov_inter=0	Gov_inter=1	Gov_inter=0
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
I_1 x ($P_{i,t-1}$ - $HAP_{i,t-1}$)ros	-0.0798***	-0.0054			-0.1086***	0.0123			-0.0957***	0.0024		
	(-4.0974)	(-0.2688)			(-4.9110)	(0.6992)			(-5.7192)	(0.1066)		
I_2 x ($IP_{i,t-1}$ - $SAP_{i,t-1}$)ros			-0.0481***	-0.0292			-0.0678***	0.0107			-0.0955***	-0.0107
			(-3.6595)	(-1.4896)			(-4.6052)	(0.6417)			(-6.4034)	(-0.7025)
Debtratio	0.0089	0.0152	0.0053	0.0133	0.0071	0.0143	0.0033	0.0150	0.0209**	0.0021	0.0144	0.0008
	(0.8333)	(1.2370)	(0.4882)	(1.0762)	(0.5613)	(1.4919)	(0.2598)	(1.5481)	(2.2159)	(0.1761)	(1.5177)	(0.0647)
Firmsize	0.0061***	0.0029	0.0063***	0.0033	0.0036*	0.0052***	0.0038*	0.0052***	0.0030*	0.0064***	0.0040**	0.0066***
	(3.2145)	(1.4442)	(3.3196)	(1.6173)	(1.6514)	(2.8898)	(1.7462)	(2.8679)	(1.8007)	(2.9351)	(2.3521)	(3.0202)
Firmage	0.0014***	0.0008***	0.0015***	0.0008***	0.0015***	0.0006**	0.0016***	0.0006**	0.0011***	0.0010***	0.0012***	0.0010***
	(4.3491)	(2.8130)	(4.6201)	(2.6605)	(4.5283)	(2.0186)	(4.8301)	(2.0202)	(4.3194)	(2.9730)	(4.4562)	(2.9538)
Slack	0.0004	-0.0001	0.0004	-0.0001	0.0001	0.0001	0.0002	0.0001	0.0003	0.0000	0.0004	-0.0000
	(1.2630)	(-0.1630)	(1.4075)	(-0.1608)	(0.3291)	(0.2728)	(0.5286)	(0.2542)	(1.0316)	(0.0001)	(1.1573)	(-0.0227)
HHI	0.0380	0.0194	0.0253	0.0199	0.0341	0.0338	0.0174	0.0335	0.0351	0.0135	0.0236	0.0132
	(0.8765)	(0.3455)	(0.5839)	(0.3553)	(0.6746)	(0.6209)	(0.3429)	(0.6160)	(0.9071)	(0.2441)	(0.6125)	(0.2383)
Shrcr	0.0393***	-0.0004	0.0389***	-0.0007	0.0337*	0.0085	0.0332*	0.0085	0.0560***	-0.0054	0.0552***	-0.0054
	(2.6122)	(-0.0276)	(2.5815)	(-0.0477)	(1.8690)	(0.7004)	(1.8340)	(0.6995)	(4.3522)	(-0.3447)	(4.3086)	(-0.3439)
CEOduality	0.0027	0.0033	0.0027	0.0032	0.0006	0.0044	0.0007	0.0044	0.0051*	-0.0017	0.0053*	-0.0017
	(0.7765)	(0.9027)	(0.7882)	(0.8852)	(0.1488)	(1.4498)	(0.1588)	(1.4567)	(1.7714)	(-0.4228)	(1.8582)	(-0.4097)
Boardsize	-0.0053	-0.0066	-0.0069	-0.0061	-0.0107	-0.0062	-0.0135	-0.0061	-0.0114	-0.0145	-0.0138	-0.0144
	(-0.4198)	(-0.5977)	(-0.5447)	(-0.5556)	(-0.7783)	(-0.6084)	(-0.9837)	(-0.6035)	(-1.0138)	(-1.2188)	(-1.2296)	(-1.2091)
Indepdirector	-0.0178	0.0399	-0.0180	0.0407	-0.0899**	0.0657**	-0.0906**	0.0657**	-0.0238	0.0096	-0.0288	0.0091
	(-0.4774)	(1.2202)	(-0.4808)	(1.2454)	(-2.0977)	(2.2581)	(-2.1116)	(2.2595)	(-0.7479)	(0.2594)	(-0.9057)	(0.2468)
Subsidy	0.0047***	0.0002	0.0046***	0.0003	0.0066***	-0.0003	0.0064***	-0.0004	0.0001	0.0050***	0.0001	0.0051***
	(3.5457)	(0.1363)	(3.4892)	(0.1999)	(4.3125)	(-0.2874)	(4.2367)	(-0.3132)	(0.0604)	(3.6485)	(0.1262)	(3.6638)
Constant	-0.0006**	0.0006***	-0.0005**	0.0006***	-0.0008***	0.0007***	-0.0007**	0.0007***	0.0002	-0.0000	0.0002	-0.0000
	(-2.2106)	(2.6332)	(-1.9829)	(2.6356)	(-2.7939)	(3.1103)	(-2.4623)	(3.0897)	(0.5623)	(-0.0904)	(0.6610)	(-0.0715)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.1185	0.0766	0.1165	0.0780	0.1279	0.0743	0.1259	0.0743	0.1048	0.0906	0.1100	0.0909
N	1942	1721	1942	1721	1806	1857	1806	1857	1731	1932	1731	1932
Coefficient test	2.77*(0.0958)		0.41(0.5207)		5.57**(0.0182)		2.71*(0.0995)		4.20**(0.0405)		3.84*(0.0500)	

*Note: ROS is used as a performance proxy to calculate historical negative feedback and social negative feedback, ordinary least squares (OLS) is used to estimate the model, and all variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

Table A4. Robust regression with varying samples: Baseline regression results.

	Dependent variable =R&D efficiency		
Variables	(1)	(2)	(3)
I_1 x ($P_{i,t-1}$ - $HAP_{i,t-1}$)		-0.0587*	
		(-1.8532)	
I_2 x ($IP_{i,t-1}$ - $SAP_{i,t-1}$)			-0.1304***
			(-7.3926)
Debtratio	0.0087	0.0082	0.0030
	(1.2281)	(1.1541)	(0.4325)
Firmsize	0.0042***	0.0043***	0.0050***
	(3.2584)	(3.3448)	(3.9053)
Firmage	0.0009***	0.0008***	0.0008***
	(4.4442)	(4.3648)	(4.1300)
Slack	0.0002	0.0002	0.0001
	(0.7272)	(0.6865)	(0.4577)
HHI	0.0022	0.0024	0.0030
	(0.3937)	(0.4258)	(0.5393)
Shrcr	0.0215**	0.0213**	0.0223**
	(2.2064)	(2.1891)	(2.3104)
CEOduality	0.0008	0.0009	0.0013
	(0.3639)	(0.3978)	(0.5867)
Boardsize	0.0015	0.0021	0.0012
	(0.1983)	(0.2707)	(0.1624)
Indepdirector	0.0274	0.0278	0.0249
	(1.2236)	(1.2421)	(1.1207)
Subsidy	0.0022**	0.0022***	0.0028***
	(2.5555)	(2.5901)	(3.2211)
Constant	-0.0558**	-0.0584**	-0.0702***
	(-2.2624)	(-2.3674)	(-2.8618)
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
Adjusted R^2	9.6905***	9.4477***	11.6534***
N	3059	3059	3059

*Note: Manufacturing and IT industries are selected as samples, and ordinary least squares (OLS) is used to estimate the model. All variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

Table A5. Robust regression with varying samples: regression results for regulatory mechanisms of institutional environment.

Variables	(1) Historical Inst_e=1	(2) Historical Inst_e=0	(3) Social Inst_e=1	(4) Social Inst_e=0
I_1 x ($P_{i,t-1}$ - $HAP_{i,t-1}$)	-0.1115***	0.0179		
	(-2.9650)	(0.3155)		
I_2 x ($IP_{i,t-1}$ - $SAP_{i,t-1}$)			-0.1470***	-0.0441
			(-8.1842)	(-0.8853)
Debtratio	0.0087	0.0050	0.0037	0.0024
	(1.0217)	(0.3812)	(0.4457)	(0.1803)
Firmsize	0.0040**	0.0045**	0.0047***	0.0050**

	(2.5429)	(2.0540)	(3.0042)	(2.2263)
Firmage	0.0008***	0.0009**	0.0007***	0.0008**
	(3.2794)	(2.5682)	(3.0565)	(2.4790)
Slack	0.0002	-0.0001	0.0002	-0.0002
	(0.9582)	(-0.1960)	(0.7670)	(-0.2384)
HHI	-0.0046	0.0127	-0.0032	0.0128
	(-0.6686)	(1.3114)	(-0.4692)	(1.3196)
Shrcr	0.0377***	0.0010	0.0398***	0.0006
	(3.0353)	(0.0630)	(3.2571)	(0.0410)
CEOduality	0.0018	0.0015	0.0025	0.0015
	(0.6723)	(0.3789)	(0.9414)	(0.3608)
Boardsize	0.0018	0.0017	-0.0012	0.0026
	(0.1828)	(0.1426)	(-0.1263)	(0.2159)
Indepdirector	0.0179	0.0410	0.0108	0.0423
	(0.6365)	(1.1160)	(0.3894)	(1.1530)
Subsidy	0.0028**	0.0020	0.0037***	0.0020
	(2.4449)	(1.4585)	(3.2831)	(1.4600)
Constant	-0.0452	-0.0588	-0.0537*	-0.0635
	(-1.3951)	(-1.4693)	(-1.6849)	(-1.5826)
Province	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Adjusted R^2	0.0857	0.0394	0.1150	0.0399
N	1774	1285	1774	1285
Coefficient test	2.83*(0.0924)		3.11*(0.0779)	

*Note: Manufacturing and IT industries are selected as samples, and ordinary least squares (OLS) is used to estimate the model. All variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

Table A6. Robust regression with varying samples: regression results for regulatory mechanisms of institutional factors.

	IPR Enforcement				Financial Market Development				Degree of Government Intervention			
	IPR_e=1	IPR_e=0	IPR_e=1	IPR_e=0	Fian_d=1	Fian_d=0	Fian_d=1	Fian_d=0	Gov_inter=1	Gov_inter=0	Gov_inter=1	Gov_inter=0
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$I_1 x (P_{i,t-1} - HAP_{i,t-1})$	-0.0911**	-0.0104			-0.1498***	0.0161			-0.1286***	0.0077		
	(-2.0865)	(-0.2337)			(-2.9755)	(0.4144)			(-3.3385)	(0.1624)		
$I_2 x (IP_{i,t-1} - SAP_{i,t-1})$			-0.1523***	-0.0355			-0.1723***	0.0062			-0.1466***	-0.0438
			(-7.8732)	(-0.8892)			(-8.1477)	(0.1721)			(-8.8697)	(-1.0802)
Debtratio	0.0046	0.0062	-0.0017	0.0047	-0.0013	0.0086	-0.0083	0.0087	0.0200**	-0.0043	0.0150*	-0.0067
	(0.4866)	(0.5305)	(-0.1763)	(0.4001)	(-0.1202)	(0.9179)	(-0.7777)	(0.9149)	(2.2407)	(-0.4007)	(1.7190)	(-0.6154)
Firmsize	0.0059***	0.0033*	0.0067***	0.0036*	0.0027	0.0061***	0.0031	0.0061***	0.0008	0.0066***	0.0018	0.0069***
	(3.2984)	(1.6714)	(3.7892)	(1.7821)	(1.3629)	(3.3463)	(1.6433)	(3.2986)	(0.5127)	(3.2145)	(1.1156)	(3.3783)
Firmage	0.0006**	0.0007***	0.0005*	0.0007**	0.0010***	0.0003	0.0009***	0.0003	0.0008***	0.0007**	0.0007***	0.0007**
	(2.0644)	(2.5871)	(1.8974)	(2.5207)	(3.4790)	(0.9729)	(3.4092)	(0.9640)	(3.2704)	(2.3390)	(3.0270)	(2.2772)
Slack	0.0004	-0.0003	0.0003	-0.0003	0.0003	-0.0000	0.0002	-0.0000	0.0004	0.0001	0.0003	0.0000
	(1.5074)	(-0.4392)	(1.2844)	(-0.4563)	(0.7632)	(-0.1231)	(0.4167)	(-0.1261)	(1.3464)	(0.1379)	(1.2217)	(0.0965)
HHI	-0.0051	0.0102	-0.0033	0.0102	-0.0034	0.0044	-0.0025	0.0044	0.0008	0.0050	0.0026	0.0051
	(-0.6742)	(1.2471)	(-0.4436)	(1.2440)	(-0.4047)	(0.6117)	(-0.2954)	(0.6139)	(0.1182)	(0.5780)	(0.4083)	(0.5844)
Shrcr	0.0291**	-0.0036	0.0311**	-0.0038	0.0424**	-0.0088	0.0442***	-0.0089	0.0256**	0.0061	0.0269**	0.0058
	(2.0587)	(-0.2540)	(2.2398)	(-0.2663)	(2.5413)	(-0.7314)	(2.7001)	(-0.7372)	(2.0423)	(0.4062)	(2.2019)	(0.3899)
CEOduality	0.0005	0.0012	0.0015	0.0012	-0.0050	0.0056*	-0.0042	0.0056*	0.0012	-0.0005	0.0020	-0.0004
	(0.1618)	(0.3618)	(0.5088)	(0.3474)	(-1.4349)	(1.9505)	(-1.2089)	(1.9517)	(0.4605)	(-0.1279)	(0.7807)	(-0.1092)
Boardsize	-0.0005	0.0025	-0.0035	0.0028	0.0090	0.0031	0.0067	0.0032	-0.0184*	0.0133	-0.0216**	0.0139
	(-0.0411)	(0.2460)	(-0.3064)	(0.2737)	(0.7514)	(0.3167)	(0.5710)	(0.3298)	(-1.7602)	(1.2259)	(-2.1119)	(1.2763)
Indepdirector	0.0081	0.0532*	-0.0021	0.0539*	-0.0036	0.0772***	-0.0135	0.0774***	-0.0109	0.0403	-0.0176	0.0404
	(0.2385)	(1.7666)	(-0.0621)	(1.7907)	(-0.0982)	(2.7922)	(-0.3783)	(2.7979)	(-0.3722)	(1.2245)	(-0.6173)	(1.2275)
Subsidy	0.0040***	0.0005	0.0049***	0.0006	0.0057***	-0.0004	0.0068***	-0.0004	0.0012	0.0035***	0.0023**	0.0036***
	(3.3414)	(0.4303)	(4.1598)	(0.4634)	(4.1470)	(-0.3950)	(5.0836)	(-0.4012)	(1.0610)	(2.7229)	(2.0766)	(2.7417)
Constant	-0.1040**	-0.0827*	-0.1136***	-0.0875*	-0.1136*	-0.1023**	-0.1278**	-0.1026**	-0.0112	-0.1058**	-0.0228	-0.1088**
	(-2.3817)	(-1.6641)	(-2.6492)	(-1.7541)	(-1.8088)	(-2.2763)	(-2.0763)	(-2.2779)	(-0.2682)	(-2.1287)	(-0.5592)	(-2.1881)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.1573	0.1008	0.1881	0.1013	0.1783	0.0790	0.2110	0.0789	0.1798	0.1091	0.2182	0.1098
N	1567	1492	1567	1492	1435	1624	1435	1624	1417	1642	1417	1642
Coefficient test	2.41(0.1208)		6.54** (0.0105)		5.57**(0.0182)		2.71*(0.0995)		4.90**(0.0269)		6.56**(0.0104)	

*Note: Manufacturing and IT industries are selected as samples, and ordinary least squares (OLS) is used to estimate the model. All variables are defined as above. Z/T statistics are reported in parentheses. *, ** and ** are significant at 10%, 5% and 1% levels, respectively.*

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