The two faces of R&D investments: push and pull factors

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Abstract: Prior research has examined how financial constraints and agency costs affect the allocation of investment in research and development (R&D). However, we still know little about the effect of both factors simultaneously. It is important to investigate this to determine whether the *pull* or *push* effect dominates in R&D investment allocation and to determine the causes and extent of R&D investment inefficiency further. While the pull effect reduces investment, the push effect encourages firms to invest more in R&D. The two-tier frontier model was used to examine data from Chinese listed firms from 2009 to 2014. The results indicate that agency costs (the *push* effect) are the predominant cause of R&D investment inefficiency. The *push* effect causes 87.97% of Chinese firms to overinvest and leads to an average overinvestment of 41.33% above the optimal level. Moreover, this R&D investment inefficiency is heterogeneous in terms of state ownership structures. A higher percentage of state-owned firms suffer from severe overinvestment. We also found that agency costs result from the principal-principal (PP) and not principal-agent (PA) conflicts in China.

Keywords: R&D investment; agency costs; financial constraints; inefficiency; China.

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1 Introduction

In the context of firms' long-term success, research and development (R&D) play a crucial role, as it can contribute to firms' capabilities to innovate and fight obsolescence. Firms in emerging countries are investing in R&D, as they believe this can help them attain the level of their competitors in the West. According to the 2016 Global Innovation 1000 report published by PricewaterhouseCoopers (PwC), Chinese firms made the most significant R&D expenditure in 2016, with the 130 Chinese companies listed in the report having invested a total of $48.6 billion. Scholars have investigated even further and found that R&D expenditure is affected not only by *pull* factors, such as financial constraints, which reduce spending, but also by *push* factors, such as agency costs, which increase it beyond the optimal amount. These opposite forces can cause inefficiency in the allocation of R&D expenditure, leading to deviations from the optimal level. However, understanding of which force causes the greatest R&D investment inefficiency in Chinese firms remains elusive.

Previous studies have suggested that firms' R&D expenditure is driven by their financial capacities. Financial constraints arise when firms are raising external funds, which are more expensive than internally generated funds (Poncet et al., 2010). Thus, the scarcity of internal capital *pulls* R&D investment below the optimal level (Li, 2011; Czarnitzki and Hottenrott, 2011). Conversely, R&D investment could be *pushed* to exceed the ideal conditions by agency costs. For example, there is the possibility of moral hazard (Jensen, 1986) or a principal-agent (PA) conflict. Some managers tend to allocate funds to projects that benefit them, rather than those that contribute to the profits of shareholders. Managers prefer to retain control over larger firms and direct funds to pet projects that offer them greater private benefits (Shin and Kim, 2002). These empire-builders tend to overinvest in R&D since these projects are long-term commitments that can secure their positions. In addition, it is challenging to measure the outcomes of R&D projects and offer easy returns to managers (Li, 2011). On the other hand, agency costs can result from the principal-principal (PP) conflicts between minority and controlling shareholders. PP problems emerge when firms have concentrated ownership (La Porta et al., 1999b) and cash-flow rights and control rights are split (Lin et al., 2011). In order to obtain expropriation from minority shareholders, controlling shareholders tend to overinvest in R&D in the firms with PP conflicts (Shleifer and Vishny, 1997).

Although *push* and *pull* factors coexist, as far as we know, studies that investigate both simultaneously are limited. Specifically, if agency costs and financial constraints both lead to investment deviation, which factor is likely to have greater influence? Examining the effect of these conflicting *pull* and *push* forces can lead to different explanations of R&D inefficiency (Lin et al., 2017). If the *pull* effect dominates, firms invest less than the optimal level; however, if the *push* effect has greater influence, firms overinvest. Moreover, do firms with different state ownership structures have differences in inefficiency? The answers to these questions are essential for Chinese firms, especially large ones (e.g., Huawei, Lenovo) that are currently part of the international innovation network, as well as others that are attempting to engage in R&D activities beyond China's boundaries.

In this study, we used data on Chinese publicly listed firms from 2009 to 2014 and adopted two-tier stochastic frontier analysis (two-tier SFA) to solve the research gap. The expected investment model proposed by Richardson (2006) was used to predict optimal R&D investment by considering both financial constraints and agency costs. The two-tier SFA can determine the extent to which financial R&D investment is *pulled* or *pushed* away from the optimal level (Kumbhakar and Parmeter, 2009). More importantly, this model does not need to assume that a firm suffers from financial constraints or agency costs (Kumbhakar and Tsionas, 2011). This assertion provides flexibility and reduces the complexity of ascertaining whether the firm has financial constraints or agency costs.

This study makes contributions on two fronts. First, theoretically, we considered both financial constraints and agency costs in making R&D investments. Although scholars have focused on R&D investments by focusing either on financial constraints (Czarnitzki and Hottenrott, 2011; Li, 2011) or on agency costs (Lee and O'Neill, 2003), we continue to have a limited understanding of how firms can invest efficiently in R&D, when these two conflicting factors are taken into consideration. Firms suffer from financial constraints and agency costs simultaneously, making a focus on either factor inadequate in predicting R&D. Moreover, previous studies (e.g., Lin et al., 2017) have emphasised the PA conflict as the only source of agency costs while ignoring the conflicts between large and minority shareholders that dominate the emerging countries. Second, from an empirical perspective, the ordinary linear squares (OLS) and frontier approaches are not suitable for calculating the inefficiency caused by conflicting factors or deciding which factor contributes more to this inefficiency. To solve this problem, we used a two-tier SFA of R&D investment research to calculate the total and net effect of both the *pull* and *push* factors simultaneously.

2 Theoretical background

2.1 R&D expenditure as a firm investment

R&D investment remains investment within firms' boundaries; thus, it also suffers from the constraints and advantages of a general investment model. However, R&D investment also differs from ordinary capital expenditure by three distinct means. First, R&D investment is accompanied by high risk, due to the uncertain output. This uncertainty implies that R&D investments are not a simple matter of specific distribution with a mean and variance (Hall and Lerner, 2010). Moreover, the low success rate of R&D projects also increases the firm's risks (Lee and Cin, 2010). Second, R&D investments may result in positive externality. The salaries of scientists or engineers account for the most significant part of the cost. The output of R&D investment is created by the efforts of these specialists: knowledge that is intangible and tacit (Hall and Lerner, 2010); however, this knowledge is not trivial. One single firm cannot exclude the use of knowledge by another (Huizingh, 2011). That is to say, the output of R&D investments is not secret and can spill over beyond firms' boundaries. Third, R&D investments have high adjustment costs. There is usually a considerable time gap between conception and commercialisation (Wang and Wu, 2012). As a result, firms need to provide a smooth flow of investment to R&D projects to maintain the research team's focus and to maintain the knowledge that the R&D team has created (Hall et al., 2010). If scientists and engineers leave the company, most endeavours will be in vain.

Because of these three characteristics, the financing market for R&D projects takes the form of a 'lemon's market' (Akerlof, 1970). External investors demand higher returns for investments in R&D, as they cannot ascertain the quality of projects because of information asymmetry (Czarnitzki and Hottenrott, 2011). Since differences exist between the returns expected by an entrepreneur's investment and the returns expected by external investors, firms prefer to use internal funds to finance R&D projects (Choi et al., 2015). Thus, firms' R&D investments are affected by financial constraints. Moreover, firms suffer from type I agency costs, resulting from conflicts between owners and managers, and type II agency costs, resulting from differences between minority and controlling shareholders. These agency costs can also lead to an inefficient allocation of investment (Jensen and Meckling, 1976). Minimal evidence has suggested that firms can be solely affected by one factor and can be immune to the other. Firms' R&D expenditure is, thus, expected to be influenced by both *pull* and *push* factors.

2.2 Financial constraints and R&D investments

The model for investment used in this study utilises the work of Modigliani and Miller (1958). According to these authors, financing and investments are independent in perfect capital markets. In this case, the investment model usually assumes that firms can obtain external funds in capital markets with the same costs as with internal funds (Berk et al., 2004). However, capital markets are not perfect. External investors do not have the information that managers and CEOs have regarding their projects when facing information asymmetry. Thus, investors will request a higher premium for the investment. This request will result in external funds being more expensive than internal funds; thus, firms prefer internal funds to finance investment. In most cases, internal capital is limited; when firms encounter financial constraints, this will lead to underinvestment (Fazzari et al., 1988).

There are two reasons why firms may suffer more from financial constraints when they use internal funds to conduct an R&D project (Mohnen et al., 2008; Carboni, 2017). First, R&D projects are intangible activities, making them difficult for the mortgage (Hall, 1993). For banks and other debtholders, physical assets are the best choice to secure their loan. As the output of R&D activities is knowledge, which is difficult to measure, these debtholders are less willing to lend money to firms for R&D projects. Second, due to the 'lemon' risk, investors will demand higher compensation (Hall et al., 2010). Compared with regular investment opportunities, R&D projects suffer more from information asymmetry. Because of higher risks, positive externalities and high adjustment costs, the outcomes of R&D projects are even harder to predict. This finding increases the concerns of investors and drives up the cost of raising external funds (Hall, 2002; Mohnen et al., 2008).

Empirical studies provide evidence of firms' preference for funding R&D projects through internal funds. Research has proved that R&D projects are more sensitive than physical investments to corporate cash flow (CF). Brown and Petersen (2011) found that firms will encounter financing friction when they are heavily dependent on cash holdings to finance R&D projects. Using firm data from Denmark, Bloch (2005) found that R&D investments are affected by internal funds, which implies the existence of credit market imperfections. Czarnitzki and Hottenrott (2011) found that when firms use internal funds to conduct R&D engagements, they underinvest in R&D because of a lack of internal capital. Using data from German firms, Müller and Zimmermann (2009) found that external equity can help reduce firms' financial constraints and can thus support the financing of R&D activity. Generally, Fazzari et al. (1988) believed that firms are unwilling to use internal capital to make R&D investments when facing financial constraints, which would result in underinvestment.

2.3 Agency costs and R&D investment

When ownership and control are separated in a firm's organisational structure, as is often the case, PA conflicts arise between owners and managers. A firm with highly dispersed shareholders may experience a 'free-rider effect', which will reduce the efficiency of manager monitoring. Since they lack the power to monitor managers closely, shareholders are less likely to associate firm performance with managerial decisions. This issue leads to managers undertaking self-maximising actions to build their empires. Similarly, firms' resources may not be allocated efficiently and can reduce firm value. Managers prefer to overinvest in projects; in addition, those in control of larger firms may overinvest, as these actions may lead to higher prestige, status, power and compensation for them (Hope and Thomas, 2008). In the 'free cash flow' (FCF) theory, Jensen (1986) indicated that managers prefer to invest the FCF into projects that have low or even negative net present values (NPV) to increase their control over resources.

Conversely, when there is an increase in the concentrated ownership of a firm, PP conflicts arise between controlling and minority shareholders. It is typically the case in emerging economies where institutional infrastructure is weak. In this situation, it is hard to protect minority shareholders' legal rights and interests (Dharwadkar et al., 2000). In most PP conflicts, there is a wedge between the cash-flow rights and the control rights of controlling shareholders (Francis et al., 2005). Thus, larger shareholders could reallocate firms' resources for private benefits of control (PBC) while bearing limited risk for such activities (Lin et al., 2011). In other words, controlling shareholders can take greater risks because they can obtain personal gains while leaving the risks of R&D and failure of investment to minority shareholders (Shleifer and Vishny, 1997). As R&D investments are accompanied by high risk as well as high potential returns, controlling shareholders are more likely to use their rights to overinvest in these projects.

Empirical studies provide evidence that both types of agency costs exist in R&D decisions. Block (2012) found that family ownership discourages R&D investment, indicating that greater agency costs can lead to greater R&D expenditure. Chrisman and Patel (2012) extended the concept to non-family firms and found that firms with agency problems prefer to overinvest in R&D projects. Moreover, Joseph and Richardson (2002) found that firms with PP problems are more likely to be aggressive and overinvest in multiple projects. These results indicate that PP conflicts cause overinvestment in R&D projects. Generally, research has found that, in the case of PA conflicts, managers tend to overinvest to increase their prestige (Stulz, 1990) and compensation (Arye Bebchuk and Fried, 2003) and to reduce the unemployment rate (Amihud and Lev, 1999). These personal incentives tend to raise R&D investments above their optimal levels (Hall, 2002).

However, it is difficult to determine whether a *pull* or *push* factor has a greater effect on R&D expenditure. Generally, Fazzari et al. (1988) found that firms' R&D investments are driven by internal CF, which proves the effect of financial constraints. In contrast, Kaplan and Zingales (1997) found the contrary result of FTP 1988. These researchers' findings implied that, with high agency costs, firms without financial constraints are likely to overinvest and are also likely to exhibit substantial investment-CF sensitivity. Hadlock (1998) findings indicated that firms' investments are affected by both financial constraints and agency costs.

Although financial constraints and agency problems influence R&D expenditure on two different fronts, they all depend on the Berle-Means proposition (Means and Berle, 1932). These authors suggested that modern firms are characterised by the dispersion of ownership and control across small, dispersed shareholders. Because of these traits, shareholders with minor equity tend to be 'free riders', which results in the insufficient monitoring of managers. This result can lead to PA conflicts. Conversely, controlling shareholders can acquire PBC at the cost of minority shareholders, even with legal approaches. This finding can lead to PP conflicts. Moreover, when large shareholders have concentrated control, this can lead to information asymmetry between firms and the external market, which will lead to financial constraints (Morellec et al., 2012). Thus, financial constraints can also be understood as PA problems between external investors and the firms' decision-makers (Jensen and Meckling, 1976).

3 Methods and data

3.1 Sample sources

Our sample consisted of firms listed on the Shanghai and Shenzhen stock exchanges 2009–2014 (mainboard only). The data come from two different sources. First, the R&D investment data for each firm originate from the China Center for Economic Research (CCER) database. The financial data were retrieved from the China Stock Market and Accounting Research (CSMAR) database.

3.2 Econometric model

The traditional Q theory holds that if the capital market is perfect and managers aim to maximise firms' value. As a result, investment is solely dependent on investment opportunities. However, in reality, when a firm encounters severe information asymmetry, its external financing is significantly more expensive than internal financing, which will lead to insufficient R&D investment; that is, the company's actual investment will be less than the optimal level. Conversely, agency costs (due to either PP or PA conflicts) will also result in excessive investment; that is, the company's spend on R&D will be above its optimal level. As both these scenarios have unilateral distribution characteristics, we used the bilateral two-tier SFA model to describe the company's R&D investment,

$$I_{it} = I_{it}^{*} + \varepsilon_{it}, \varepsilon_{it} = v_{it} - u_{it} + w_{it} \quad (1)$$

where I_{it} represents the actual R&D investment and $I_{it}^{*} = \delta X_{it}^{\prime}$ represents the optimal investment level determined by the R&D investment opportunity, where v_{it} represents the residual, which reflects the unpredictable factors that lead to random deviations from the optimal investment amount. $u_{it} \geq 0$ and $w_{it} \geq 0$ represent the financing constraints and agency costs that lead to deviations from the optimal investment amount in opposite directions. If $u_{it} = 0$, this means that the firm encounters only agency costs. If $w_{it} = 0$, this means that the firm encounters only financial constraints. If $u_{it} = w_{it} = 0$, equation (1) becomes the investment decision model under perfect conditions. Although u_{it} and w_{it} may be zero, the expectation of the composite residual may not be zero. OLS estimation is not suitable for equation (1). Hence, the maximum likelihood estimation (MLE) approach was used to estimate the equation. As v_{it} represents random interference terms, we can assume that it is subject to the normal distribution, i.e., v_{it}~$i.d.d.$ $N(0,\ \sigma_v^2)$. Furthermore, $u_{it} > 0$ and $w_{it} > 0$, which indicates that they are non-negative random interference terms. We can assume these terms are subject to an exponential distribution, i.e., u_{it}~$i.d.d.$ $\exp(0,\ \sigma_u^2)$, w_{it}~$i.d.d.$ $\exp(0,\ \sigma_w^2)$. Finally, we assume that the three interference terms are independent of each other and are not related to the explanatory variables. According to the above assumptions, the distribution density function of compound interference can be deduced:

$$\begin{aligned} f(\varepsilon_{it}) &= \frac{\exp(a_{it})}{\sigma_u + \sigma_w}\Phi(c_{it}) + \frac{\exp(b_{it})}{\sigma_u + \sigma_w}\int_{-d_{it}}^{\infty} \varphi(z)dz \\ &= \frac{\exp(a_{it})}{\sigma_u + \sigma_w}\Phi(c_{it}) + \frac{\exp(b_{it})}{\sigma_u + \sigma_w}\Phi(d_{it}) \end{aligned} \tag{2}$$

where φ ( ) and Φ ( ) indicate probabilistic density and cumulative distribution of standard normal distribution, respectively. The following parts display other parameters:

$$\begin{aligned} a_{it} &= \frac{\varepsilon_{it}}{\sigma_u} + \frac{\sigma_v}{2\sigma_u};\ b_{it} = -\frac{\varepsilon_{it}}{\sigma_w} + \frac{\sigma_v}{2\sigma_w} \\ c_{it} &= -\left(\frac{\varepsilon_{it}}{\sigma_v} + \frac{\sigma_v}{2\sigma_u}\right);\ d_{it} = \frac{\varepsilon_{it}}{\sigma_v} - \frac{\sigma_v}{\sigma_w} \end{aligned} \tag{3}$$

According to the distribution density of the composite residual, the logarithmic MLE can be constructed corresponding to *it* observations:

$$\ln L(x_{it};\theta) = -\ln(\sigma_u + \sigma_w) + \ln\left[\exp(a_{it})\Phi(c_{it}) + \exp(b_{it})\Phi(d_{it})\right] \tag{4}$$

where $\theta = \{\beta, \sigma_v, \sigma_u, \sigma_w\}$ are the estimated parameters. As σ_u only appears in a_{it} and c_{it}, and σ_w only appears in b_{it} and d_{it}, all the parameters can be estimated by using the maximising likelihood function. After obtaining the estimates for all the parameters, we used the likelihood ratio (LR) test to examine whether financial constraints and agency costs affect investments. The LR statistic is as follows:

$$LR = -2\left[L(H_0) - L(H_1)\right] \tag{5}$$

where $L(H_0)$ and $L(H_1)$ correspond to the logarithmic likelihood values under the original assumption and the alternative assumption.

To obtain the point estimation of each company's u_{it} and w_{it}, the conditional distribution of u_{it} and w_{it} should be deduced first as follows:

$$f\left(u_{it}\left|\varepsilon_{it}\right.\right)=\frac{\lambda\exp\left(-\lambda u_{it}\right)\Phi\left(u_{it}/\sigma_v+d_{it}\right)}{X_{1it}} \tag{6}$$

$$f\left(w_{it}\left|\varepsilon_{it}\right.\right)=\frac{\lambda\exp\left(-\lambda w_{it}\right)\Phi\left(w_{it}/\sigma_v+c_{it}\right)}{X_{2it}} \tag{7}$$

where $\lambda=\frac{1}{\sigma_u}+\frac{1}{\sigma_w}$, $X_{1it}=\Phi(d_{it})+\exp(a_{it}-b_{it})\Phi(c_{it})$ and Xsit = $\exp(b_{it}-a_{it})X_{1it}$.

From equations (6) and (7), the conditional expectation of u_{it} and w_{it} can be deduced as follows:

$$E\left(u_{it}\left|\varepsilon_{it}\right.\right)=\frac{1}{\lambda}+\frac{\exp\left(a_{it}-b_{it}\right)\sigma_v\left[\Phi\left(-c_{it}\right)+c_{it}\Phi\left(c_{it}\right)\right]}{X_{1it}} \tag{8}$$

$$E\left(w_{it}\left|\varepsilon_{it}\right.\right)=\frac{1}{\lambda}+\frac{\sigma_v\left[\Phi\left(-d_{it}\right)+d_{it}\Phi\left(d_{it}\right)\right]}{X_{2it}} \tag{9}$$

Since the estimations of equations (8) and (9) are the absolute deviations between the actual and the optimal investment of each firm, the values cannot be compared between firms. To get the deviation between actual investment and optimal investment, we convert these equations as follows:

$$\begin{aligned}&E\left(1-e^{-u_\sigma}\left|\varepsilon_{it}\right.\right)=1\\&-\frac{\lambda}{1+\lambda}\frac{1}{X_{1it}}\left[\Phi\left(d_{it}\right)+\exp\left(a_{it}-b_{it}\right)\exp\left(\frac{\sigma_v^2}{2}-\sigma_v c_{it}\right)\Phi\left(c_{it}-\sigma_v\right)\right]\end{aligned} \tag{10}$$

$$\begin{aligned}&E\left(1-e^{-w_\sigma}\left|\varepsilon_{it}\right.\right)=1\\&-\frac{\lambda}{1+\lambda}\frac{1}{X_{2it}}\left[\Phi\left(c_{it}\right)+\exp\left(b_{it}-a_{it}\right)\exp\left(\frac{\sigma_v^2}{2}-\sigma_v d_{it}\right)\Phi\left(d_{it}-\sigma_v\right)\right]\end{aligned} \tag{11}$$

where equations (10) and (11) are used for measuring the expenditure below and above the optimal level. For the convenience of presentation, equations (8) and (9) are expressed as financing constraints indicator (FCI) and agency cost indicator (ACI). Correspondingly, equations (10) and (11) are expressed as percentage of financing constraints indicator (PFCI) and percentage of agency cost indicator (PACI). The above four equations show that there is no need for a prior grouping of samples, and the insufficient investment sample and the degree of overinvestment are entirely determined by the estimation results. Finally, this paper further defines the net effect indicator and the percentage indicator of financing constraints and agency costs as *NI = ACI – FCI*, while *PNI = PACIs – PFCI*.

3.3 Model specification

We adopted Richardson (2006) expected investment model to estimate the optimal level of R&D investment for a firm for two reasons. First, because of market imperfections, the optimal investment level cannot be represented by Tobin's Q. This finding is especially common in emerging countries (Young et al., 2008). Second, it is difficult to find other variables with which to predict firms' investment opportunities. Thus,

$$\begin{aligned} I_{it} &= \beta_0 + \beta_1 Patent_{i,t-1} + \beta_2 Age_{i,t-1} + \beta_3 Debt_{i,t-1} + \beta_4 Cash_{i,t-1} \\ &\quad + \beta_5 Size_{i,t-1} + \sum Industry + \sum Year + v_{it} - u_{it} + w_{it} \end{aligned} \tag{12}$$

where $Patent_{i,t-1}$, $Age_{i,t-1}$, $Debt_{i,t-1}$, $Cash_{i,t-1}$ and $Size_{i,t-1}$ is the number of patent applications, firm age, firm debts, cash holdings and firm size in a given year. The number of patents held by a firm has been found to be positively related to firms' research programs, thus contributing to R&D expenditure (Jaffe, 1986). Firm age and size are general firm characteristics that have been found to be relevant to various firms' strategies including investment decisions (Adelino et al., 2017). Firms' debts and cash holdings are important factors in the prediction of firms' investments in various investment models. Recently, He and Wintoki (2016) found that firms' cash holdings are associated with firms' R&D expenditure in US firms. Lewis and Tan (2016) found that R&D investments have positive relationships with the choice between equity and debt. Finally, we also controlled for the effect of year and industry.

Positive CF may help firms significantly reduce the extent of their financial constraints (Kaplan and Zingales, 1997). Moreover, firms can obtain more internal funds by tapping into their net liquid assets (NLAs) (Bacchetta and Benhima, 2015). Thus,

$$\begin{aligned} \sigma_u &= \exp(\delta_u) \\ \delta_u &= \alpha_0 + \alpha_1 CF_{it} + \alpha_2 NLA_{it} \end{aligned} \tag{13}$$

where CF_{it} and NLA_{it} are firms' CF and NLAs. On the one hand, firms with more FCF suffer more from PA agency costs (Jensen, 1986). On the other hand, firms suffer more from PP agency costs if controlling rights and cash-flow rights are split between minor and major shareholders. Thus, the control–ownership wedge can be a proxy for type II agency costs (Lin et al., 2011). Thus,

$$\begin{aligned} \sigma_w &= \exp(\delta_w) \\ \delta_w &= \beta_0 + \beta_1 FCF_{it} + \beta_2 DEV_{it} \end{aligned} \tag{14}$$

where FCF_{it} and DEV_{it} are the FCF and the controlling shareholders' deviation between ownership and control.

3.4 Measurements

In this section, we introduce the definitions of the variables. For the expected investment model, *I* is the R&D investment ratio, defined as R&D investment divided by fixed asset net value. The *patent* is the number of patent applications. *Age* is equal to the current year minus the founding year. *Debt* is measured as debt divided by total assets. *Cash* is measured as money funds divided by the net value of fixed assets. *Size* is measured as the logarithm of total assets. *Industry* and *year* are the dummies of firms' industry and year.

For the two-tier SFA, as shown in equations (13) and (14), *CF* is calculated as net CF divided by fixed asset net value. *NLAs* are calculated as current assets minus current debts, divided by fixed asset net value. Control-ownership wedge (*DEV*) is the difference between the control rights and the cash-flow rights of the ultimate owners of the firm. In our study, in accordance with the process used in the previous literature, we calculated control rights and cash-flow rights (Lin et al., 2011). *FCF* is defined as FCF divided by fixed asset net value.

Finally, we also investigated the heterogeneity between different state ownership structures and across the different region's firms are located in. State ownership is the dummy variable. We measured state ownership as 1 if the firm is owned by the Chinese government, and 0 otherwise (Wang et al., 2008).

4 Results

Table 1 provides the variables' descriptive statistics. The sample included data from 1,454 firms from 2009 to 2014. The total number of observations in the sample was 5,014. Moreover, we also reported the operationalisation of each variable in Table 1. To avoid outliers, we winsorised each variable at 1%.

4.1 Full sample results

The results of the two-tier SFA using the full sample are displayed in Table 2. Specifically, model 1 uses an OLS estimation to model how R&D investment is affected by the five variables we mentioned. From model 1, the patent application is positively associated with R&D investment. This finding indicates that firms invest more in R&D as their experience increases. Firms with higher debt and cash holdings prefer R&D projects. Finally, we found that small firms prefer to conduct more R&D projects.

Models 2 to 5 use MLE to estimate the two-tier SFA model with different settings to select models that fit our data. In model 2, we set both $\delta_u = \alpha_0$, $\delta_w = \beta_0$. In this case, the *pull* and *push* factor drive R&D investment away from the optimal level, which causes inefficiency. However, the effects are homogeneous. In model 3, we set $\delta_w = \beta_0$, where financial constraints are determined and estimated through equation (13). Model 3 shows that the coefficients of CF and NLAs are negative and significant at 10% and 5%, respectively. This result indicates that, with higher CF and more NLAs, firms will encounter lower financial constraints. In model 4, we set $\delta_u = \alpha_0$, where agency costs are determined and estimated through equation (14). We can see in model 4 that the coefficient of the control-ownership wedge is positive and significant, while the coefficient of FCF is not statistically significant. This finding indicates that more substantial differences between controlling shareholders' control rights and cash-flow rights enhance the likelihood of agency costs. However, it appears that agency costs are not related to PA conflicts. In model 5, we set the financial constraints and agency costs simultaneously through a combination of equations (13) and (14) and included the industry and year dummies. As with models 3 and 4, the effects of financial constraints and agency costs are consistent. To select the best model to fit our data, we estimated the log-likelihood (LL) of models 2, 3, 4 and 5. The LL of model 5 is the largest, indicating that model 5 fits the data best. We also conducted LR tests of models 3, 4 and 5 and compared these with model 2. The LR values increase and are statistically significant, indicating that model 5 best fits the data. Thus, we provide the following results based on model 5.

Table 1 Descriptive statistics (see online version for colours)

Variables	*Variable definition*	*Mean*	*SD*	*Min*	*Max*	*Measurement*
I	R&D investment ratio	3.900	3.046	0.180	12.860	$\frac{R\ \&\ D\ investment}{Final\ assets\_net\ value}$
Patent	Patent application	9.726	15.650	0	74	$\frac{Patent\ application}{Fixed\ assets\_net\ value}$
Age	Firm age	12.151	4.806	3.000	21.000	Current year-founded year
Cash	Cash holding	3.454	5.972	0.085	28.697	$\frac{Money\ funds}{Fixed\ assets\_net\ value}$
Debt	Firm debt ratio	0.350	0.198	0.049	0.762	$\frac{Debts}{Total\ assets}$
Size	Firm size	21.545	1.015	20.014	24.213	Logarithm of total asset
CF	Cash flow	0.352	1.034	–2.048	3.899	$\frac{Net\ cash\ flow}{Fixed\ assets\_net\ value}$
NLA	Net liquid asset	4.728	8.197	–1.041	38.717	$\frac{Current\ assets - current\ debts}{Fixed\ assets\_net\ value}$
FCF	Free cash flow	0.077	1.623	–5.433	4.746	$\frac{Net\ profit + interest\ charges + non\_cash\ expenses - working\ capital - capital\ expenditures}{Fixed\ assets\_net\ value}$
Dev	Control-ownership wedge (%)	5.104	7.650	0.000	24.075	The difference between the control rights and cash-flow rights of the largest ultimate owner of the firm

Table 2 Two-tier SFA model

DV: I	*Model (1)*	*Model (2)*	*Model (3)*	*Model (4)*	*Model (5)*
	OLS	*MLE*	*MLE*	*MLE*	*MLE*
		$\delta_u = \alpha_0, \delta_w = \beta_0$	$\delta_w = \beta_0$	$\delta_u = \alpha_0$	*Basic*
Patent	0.066***	0.038***	0.041***	0.039***	0.041***
	(24.30)	(12.08)	(13.42)	(12.45)	(15.91)
Age	–0.009	–0.015***	–0.015***	–0.015***	–0.033***
	(–0.99)	(–2.90)	(–2.85)	(–2.94)	(–6.06)
Debt	4.626***	0.128	0.379**	0.139	0.879***
	(18.92)	(0.80)	(2.05)	(0.87)	(4.68)

Notes: *t* statistics in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ (two-tailed test).

Table 2 Two-tier SFA model (continued)

DV: I	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
	OLS	MLE	MLE	MLE	MLE
		$\delta_u = \alpha_0$, $\delta_w = \beta_0$	$\delta_w = \beta_0$	$\delta_u = \alpha_0$	Basic
Cash	0.016**	0.003	–0.011**	0.003	–0.020***
	(2.15)	(0.73)	(–2.29)	(0.76)	(–3.93)
Size	–0.706***	–0.470***	–0.495***	–0.477***	–0.447***
	(–14.08)	(–14.80)	(–15.23)	(–15.01)	(–13.73)
Cons	16.970***	11.191***	11.727***	11.348***	10.219***
	(16.61)	(16.75)	(17.29)	(16.99)	(14.69)
σ_v					
Cons		–0.591***	–0.627***	–0.559***	–0.579***
		(–6.95)	(–7.62)	(–6.09)	(–5.78)
σ_u					
CF			–0.111*		–0.135***
			(–1.82)		(–2.67)
NLA			–0.042***		–0.027**
			(–2.86)		(–2.46)
Cons		–1.002***	–0.714***	–0.981***	–0.574***
		(–6.37)	(–5.85)	(–6.52)	(–6.24)
σ_w					
FCF				0.013	0.007
				(1.45)	(0.78)
DEV				0.007***	0.008***
				(3.71)	(4.21)
Cons		1.120***	1.108***	1.078***	1.003***
		(57.32)	(55.65)	(48.35)	(44.56)
Year	No	No	No	No	Yes
Industry	No	No	No	No	Yes
$Adj.R^2$	0.156	-	-	-	-
Log likelihood (LL)	-	–13,675.01	–13,658.65	–11,598.42	–11,424.46
Likelihood ratio (LR)	-	-	15.28	16.63	364.35
p	-	-	0.000	0.000	0.000

Notes: *t* statistics in parentheses; **p* < 0.1, ***p* < 0.05, ****p* < 0.01 (two-tailed test).

The variance decomposition analysis of financial constraints and agency costs is reported in Table 3. This analysis estimates the explanatory power of financial constraints and agency costs to predict R&D investment inefficiency. From Table 3, we can see that the overinvestment effect of agency costs is stronger than the underinvestment effect of financial constraints. Specifically, $E(w - u) = \sigma_w - \sigma_u = 2.36$, indicating that the level of R&D investment is beyond the optimal amount in Chinese listed firms. Moreover, financial constraints and agency costs can explain 96.39% of variations, indicating that these two factors are significant in determining R&D investment inefficiency in China. Lastly, we found that, when determining R&D investment inefficiency, agency costs explain 97.08% of variances, while financial constraints only explain 2.92%. This finding suggests that agency costs have a dominant impact on R&D investment inefficiency.

Table 3 Factor decomposition analysis

	Variables definition	*Variables*	*Coefficients*
Effect estimation	Random error	σ_v	0.561
	Financial constraints	σ_u	0.495
	Agency costs	σ_w	2.853
	Total variation in R&D investment	$\sigma_v^2 + \sigma_u^2 + \sigma_w^2$	8.695
Variations decomposition analysis	Power of financial constraints and agency costs in variation	$\frac{\sigma_u^2 + \sigma_w^2}{\sigma_v^2 + \sigma_u^2 + \sigma_w^2}$	96.39%
	Power of financial constraints	$\frac{\sigma_u^2}{\sigma_u^2 + \sigma_w^2}$	2.92%
	Power of agency costs	$\frac{\sigma_u^2 + \sigma_w^2}{\sigma_v^2 + \sigma_u^2 + \sigma_w^2}$	97.08%

Table 4 reports the extracted surplus of financial constraints and agency costs based on equations (10) and (11). The main objective of estimating variances in R&D investment using a two-tier SFA function is to obtain the observation-specific estimates of surplus investment by explaining the effect of financial constraints and agency costs. i.e., by calculating $E(u|\varepsilon)$ and $E(w|\varepsilon)$, which are the surplus (in percentage) of investment due to financial constraints and agency costs compared with the optimal level of investment, $I^* = x_i\beta$. On average, agency costs increase R&D investment by 74.09% of the optimal level, while financial constraints decrease R&D investment by 32.76% of the optimal level. Thus, the net effect is to increase R&D investment to 41.33% more than the optimal level. The next three columns further report the extracted surplus at the 25th, 50th and 75th percentiles, respectively (Q1, Q2 and Q3). These data describe the heterogeneity in the surplus of R&D investment. However, the effects of agency costs dominate in all three situations. Specifically, a quarter of firms (Q1) experience overinvestment in R&D by 19.52%, and another quarter of firms (Q3) experience severe overinvestment in R&D by 67.09%.

Table 4 Surplus of financial constraints and agency cost (full sample)

Variables	*Mean*	*SD*	*Q1*	*Q2*	*Q3*
Agency cost surplus: $E(1 - e^{-w}\| \varepsilon)$	74.09	24.07	51.13	81.91	97.41
Financial constraints surplus: $E(1 - e^{-u}\|\varepsilon)$	32.76	9.58	29.46	31.36	33.37
Net surplus: $E(e^{-u} - e^{-w}\|\varepsilon)$	41.33	30.43	19.52	52.01	67.09

Figures 1, 2 and 3 graphically illustrate the surplus caused by financial constraints and agency costs and the net effects. From Figure 1, we can observe that most financial constraints' surpluses range from 20% to 40%, while most agency costs' surpluses are larger than 40%. This result means that the overinvestment caused by agency costs is more likely to impact on the allocation of R&D investment. Moreover, we can observe from Figure 3 that over 80% of firms' net surpluses in R&D investment are over 0, indicating an overinvestment in R&D. However, 12.02% of firms (603) have underinvested in R&D. In conclusion, because of the powerful impact of agency costs, most Chinese listed firms allocate more funds than necessary to R&D expenditure.

Figure 1 Histogram of financial constraints' surplus (see online version for colours)

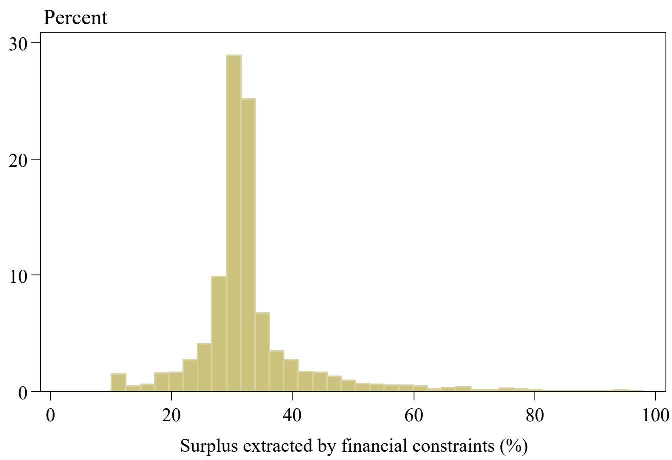
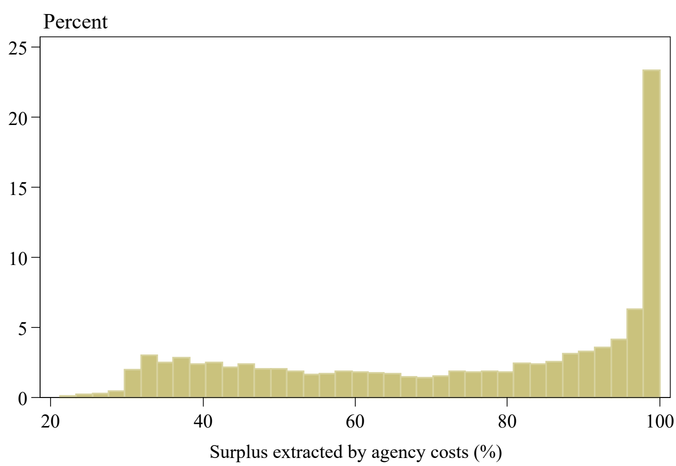


Figure 2 Histogram of agency costs' surplus (see online version for colours)



4.2 Heterogeneity of state ownership

To further investigate whether the inefficiency in the allocation of R&D spend differs across state ownership structures, we estimated the heterogeneity of state ownership based on model 5.

Figure 3 Histogram of net surplus (see online version for colours)

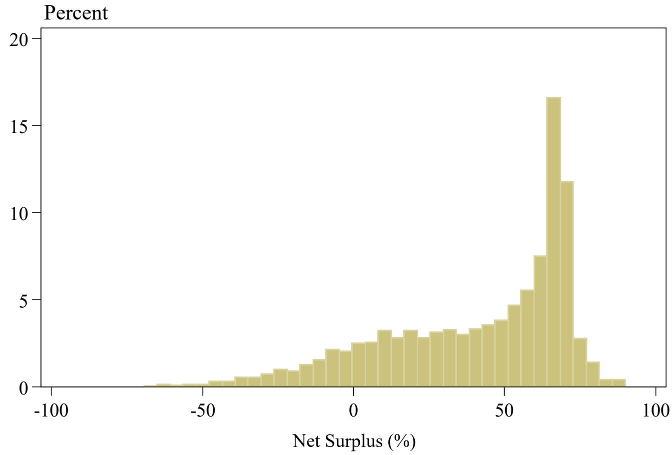


Figure 4 Histogram of net surplus of state-owned firms and non-state-owned firms (see online version for colours)

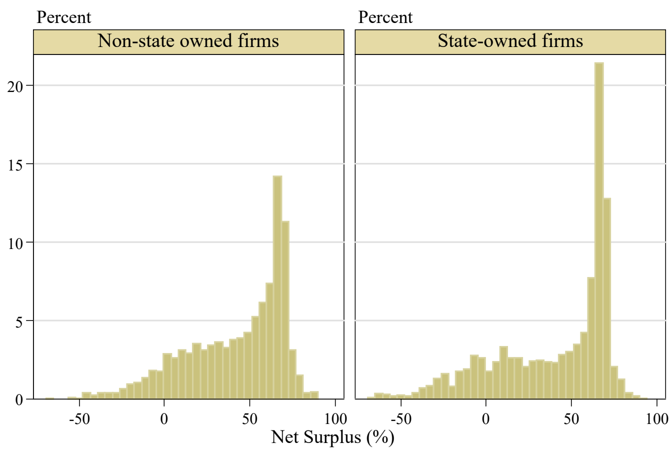


Table 5 Surplus of financial constraints and agency cost in different state ownership scenarios

	Variables	*Mean*	*SD*	*Q1*	*Q2*	*Q3*
State owned firms	Agency cost surplus: $E(1-e^{-w}\mid\varepsilon)$	74.84	25.48	48.71	85.68	98.98
	Financial constraints surplus: $E(1-e^{-u}\mid\varepsilon)$	34.70	10.88	30.50	31.75	34.82
	Net surplus: $E(e^{-u}-e^{-w}\mid\varepsilon)$	40.15	33.53	14.75	55.53	67.58
Non-state-owned firms	Agency cost surplus: $E(1-e^{-w}\mid\varepsilon)$	73.72	23.33	52.25	80.31	96.29
	Financial constraints surplus: $E(1-e^{-u}\mid\varepsilon)$	31.81	8.71	28.93	31.11	32.85
	Net surplus: $E(e^{-u}-e^{-w}\mid\varepsilon)$	41.92	28.77	21.41	50.98	66.53

As we can observe from Table 5, on average, the net surplus in non-state-owned enterprises (NSOEs) is the same as that in state-owned enterprises (SOEs). However, this net effect is heterogeneous in terms of different quantiles. In Q2 and Q3, the net effect of SOEs is larger than that of NSOEs (55.53% vs. 50.98% and 67.58% vs. 66.53%). Further investigation revealed that 54.32% of SOEs and 51.26% of NSOEs overinvest by more than 50% of the optimal level. This finding indicates that a greater percentage of SOEs suffer from severe overinvestment. Figure 4 shows a histogram of the net surplus of both types of the firm to graphically illustrate the heterogeneity in terms of state ownership. We see that a greater percentage of SOEs are overinvesting in R&D by more than 50% of the optimal level, compared to NSOEs. The surplus caused by agency costs is larger in SOEs in Q2 and Q3.

5 Discussion and conclusions

As agency costs are likely to lead to overinvestment in R&D and financial constraints to underinvestment, firms' R&D investment behaviours are more complicated when considering these conflicting variables. Specifically, which factor dominates R&D investment? Do firms experience underinvestment or overinvestment when both factors are in operation (i.e., do firms have sufficient R&D investment)? Do firms with different state ownership structures have differences in R&D investment efficiency? These questions have not been answered to date. We used data from Chinese listed firms and adopted a two-tier SFA to resolve the aforementioned questions.

This paper proves that Chinese firms are overinvesting in R&D. The overinvestment caused by agency costs is much higher than the underinvestment caused by financial constraints. Agency costs can explain over 95% of variations from the optimal level. In general, Chinese firms invest 41% more than the optimal level. However, this investment differs across state ownership structures. Specifically, NSOEs invest 41.92% more than the optimal level, while state-owned firms invest 40.15% more.

This paper investigates the overinvestment caused by agency costs. However, this effect is primarily the result of PP conflicts, not PA conflicts. This finding can be explained through the mechanisms of both conflicts. PA conflicts emerge when firms have divergent shareholders, none of whom have sufficient incentives to monitor managers' investment. This 'free-rider' effect results in PA conflicts and empire-building behaviour by managers, which further increases the extent of overinvestment. Conversely, PP conflicts arise when there is concentrated ownership. In this case, controlling shareholders have an incentive to monitor managers' investment behaviours. More importantly, when there is concentrated ownership, managers are often employed by controlling shareholders, making their interests more closely aligned (La Porta et al., 1999a). This occurrence is especially common in emerging countries (La Porta et al., 2000), such as China. Thus, PA conflicts are less likely to be the cause of overinvestment than PP conflicts.

5.1 Implications for theory

First, we suggest that further research should consider both aspects of R&D investment. Although previous studies have provided us with insightful evidence on how either financial constraints (Czarnitzki and Hottenrott, 2011; Müller and Zimmermann, 2009) or agency costs (Block, 2012; Lee and O'Neill, 2003) affect firms' R&D investment, their focus is incomplete. Since each perspective is valid to an extent, R&D investments are influenced by both financial constraints and agency costs, and the effects of overinvestment and underinvestment coexist. This study moves a step further by investigating both the pull and push effects at the same time; this provides us with a more comprehensive understanding of their independent and combined effects on R&D investment.

Moreover, agency problems should be divided into PP and PA conflicts. Most previous research on agency problems has focused on PA conflicts where firms have diluted shareholders. However, this setting is not very common in emerging economies, where firms have concentrated ownership. Firms in emerging economies suffer more from PP conflicts, and PA conflicts do not cause high agency costs in these circumstances (Young et al., 2008). We suggest that research on emerging economies should consider conflicts of both types, or at least PP conflicts, in future studies.

This study also has theoretical implications for research on state ownership. While previous research has suggested that state-owned firms can enjoy government-exclusive access to resources that confer abundant resources on them (e.g., Zhou et al., 2017), these studies ignore the fact that abundant resources can also lead to overinvestment and inefficiencies. In the R&D context, this study empirically tests and verifies the argument that a higher proportion of state-owned firms suffer from severe overinvestment. The findings exhibit a caution against the resource endowment of the state-owned firms. We suggest that governments, especially those in emerging markets, can treat SOEs and NSOEs equally and provide equal access to essential factor resources such as land and infrastructure, which can encourage state-owned firms to utilise resources more effectively.

5.2 Implications for practice

As agency costs explain most of the R&D investment inefficiency, we provide suggestions to mitigate its impact. PP conflicts arise when institutions fail to protect minority shareholders. At the macro level, legal systems should be strengthened to protect the rights of minority shareholders and to monitor controlling shareholders. We believe that laws should lay out explicit guidelines to make firms' disclosures mandatory, as this action can mitigate information asymmetry and help in the monitoring of controlling shareholders. Moreover, governments should provide equal resource access for SOEs and NSOEs; this can encourage state-owned firms to effectively utilise their resources rather than investing excessive resources.

At the micro-level, the influence of independent directors should be acknowledged. Research has verified the role of independent directors in monitoring controlling shareholders. However, Black and Kraakman (1996) proved that independent directors are not very independent in emerging countries, as controlling shareholders have the right to appoint independent directors. We believe that the reputation market of independent directors may provide information regarding the protection of minority shareholders. This approach can reduce information asymmetry, and minority shareholders can use this information to decide whether the firm's decisions are in shareholders' interests. Moreover, firms should strictly adhere to the *Establishment of Independent Director Systems by Listed Companies Guiding Opinion* issued by the China Securities Regulatory

Commission (CSRC). According to the guidelines, shareholders holding more than 1% of shares can nominate independent directors and use proxy voting to get minority shareholders involved in the appointment of independent directors.

5.3 Limitations

This paper also has some limitations. First, one limitation of our study pertains to the generalisability of our findings beyond the population from which our sample firm data were derived. The sample firms studied here are basically large, mature firms that have few similarities with small firms in terms of resource endowment and governance structure. As a result, the generalisation of the findings should be investigated further. Second, this study's findings may not match people's perception that Chinese firms have relatively low innovation capabilities. If firms are overinvesting in R&D, why do firms in China remain weak in terms of innovation? We should note that although R&D investment is a critical ingredient of innovation capability, it cannot generate innovation automatically. Recent research has suggested that dynamic capabilities such as technological diversification are the missing link between firms' resources and firms' innovation performance (Li-Ying et al., 2016). Moreover, innovation does not only involve filing patents: it also includes the commercialisation of innovative ideas (Chesbrough, 2003). Investments in R&D can enhance firms' capabilities to innovate; however, without the capacity to commercialise, Chinese firms' innovative capabilities lag behind those of their counterparts in developed countries. Further research could focus on finding variables that link R&D investment to innovation and providing suggestions on how to improve the capacity to commercialise innovation. Third, we have considered financial constraints and agency costs as two conflicting factors that affect R&D inefficiency. However, there are also other *pull* factors, such as a lack of skilled personnel, and other *push* factors, such as government subsidies, that can result in R&D inefficiency; further research should expand on this study by investigating more conflicting factors. Finally, other variables can serve as predictors of R&D investment allocation and can cause the investment amount to diverge from the optimal level. In this paper, based on previous research, we considered several factors in order to predict the optimal level of R&D investment; the model also has reasonable explanatory power. Future research could include other variables that could improve the predictive power of the expected investment model. This research could include proximity to bankruptcy (Chen and Miller, 2007) and firm slack (Chen, 2008), among other variables.

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