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R&D investment management and ambidextrous technological innovation: Evidence from Chinese listed firms☆

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ABSTRACT

Firm-level technological innovation is in part driven by R&D management motivation. This paper studies the effect of Chinese listed firms' R&D investment management on their ambidextrous technological innovation performance. In the prospective of internal financial constraints and earnings management, three R&D motivations are identified: strategically proactive intervention, resource-constrained passive adjustment, and R&D manipulation for earnings purposes. Based on the Chinese listed firm level data during 2007–2019, this paper analyzes the effects of these three different R&D management motivations on the ambidextrous innovation patent portfolio, cutting-edge innovation possibility and patent diversification. The empirical results reveal that R&D management significantly promotes ambidextrous innovation, particularly exploration innovation. Firms with more internal financial resources are more likely to engage in proactive R&D activities than those with less financial resources who are more likely to place earnings before R&D investment as the top priority. A robustness test that controls for the 2008 financial crisis also verifies our results.

1. Introduction

The current global economic situation has changed tremendously in recent years, and the rise of China has come into focus around the world. Since China put forward its innovation-driven development strategy, remarkable achievements have been made in the field of technological innovation. According to *The State of U.S. Science & Engineering* reported by the US National Science Foundation in 2020, China ranked second in the world in terms of R&D investment, and third in knowledge- and technology-intensive industrial output. The *2020 Global Innovation Index* reported by the World Intellectual Property Organization ranked China fourteenth in terms of innovation. However, it remains difficult for China to catch up with developed countries regarding innovation quality. Therefore, the *Outline of the* 14th *Five-Year Plan (2021–2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035* (P. R. China) clearly asserts that innovation should be given a core position in China's modernization efforts and that firm innovation abilities should be enhanced. Development initiatives stem from innovation activities, which are key for countries and firms to obtain sustainable and competitive advantages (Crossan & Apaydin, 2010; Rodrigues et al., 2020). Research on R&D

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investment management and technological innovation among Chinese firms can help to provide an understanding of the activities of developing countries.

Facing increasingly fierce competition, firms must seek and update their advantages through continuous innovation investments, including striking a balance between exploiting existing competencies and exploring new opportunities. However, the switch between exploitation and exploration innovations leads to unstable R&D investments, which are usually dangerous and may raise excessive conversion costs and probability of firm failure (Swift, 2016), especially in developing markets. Therefore, the first question in this study is how dynamic R&D management affects ambidextrous technological innovation, where a gap exists in the extant literature on ambidextrous innovation (He & Wong, 2004; Hughes et al., 2010; Kahn & Candi, 2021). Additionally, limited by the corporate environment and resources, firms must dynamically adjust their R&D strategies to allocate resources to innovation activities; therefore, the second research question is how corporate management motivations influence the association between R&D management and ambidextrous innovation performance, which is not analysed in the literature on R&D management (Mudambi and Swift, 2011, 2014).

R&D investment adjustment is mainly based on three management motivations, which play different roles at firm level R&D activities. The first motivation involves strategically proactive intervention. Prior studies have examined the dynamic adjustment of R&D investment from the perspective of firm innovation strategies. Mudambi and Swift (2011) point out that the volatility of R&D expenditure is due to proactive R&D management and is positively correlated with sales growth. Enterprises have ambidextrous innovation which can be classified as exploration- and exploitation-oriented R&D activities. Mudambi and Swift (2014) regard the significant and compact volatility of R&D expenditure as a visual sign of proactive R&D management, indicating that firms switch between exploration- and exploitation-oriented research efforts. Their study finds that this proactive form of R&D management can promote knowledge creation. However, further research by Swift (2016) also points out that the significant and compact volatility of R&D expenditure is positively correlated with firm mortality, which varies between firms. Research in China shows different characteristics in the relationship between R&D investment and financial performance. Wu and Xiao (2016) believe that the jump in R&D investment of Chinese firms is positively correlated with ROA (return on assets), but Jia et al. (2018) find that R&D jump demonstrates an inverted U-shaped relationship with Tobin's Q.

The second is resource-constrained passive adjustment. R&D investment is highly sensitive to internal capital endowments (James et al., 2013) because of its long innovation cycle, uncertain results (Baker & Freeland, 1975; Holmstrom, 1989), the difficulty in quantifying intangible assets and intellectual property rights (Hall & Lerner, 2010), the costs of financing, and greater information asymmetry in R&D than in other forms of investments (Knott, 2008). Therefore, external financing for R&D innovation is constrained, especially debt financing. As one main source of internal finance, operating cash flow is highly uncertain and its support for R&D can be unstable. Consequently, firms sometimes use cash reserves (Pinkowitz & Williamson, 2001; Brown and Petersen, 2011) and/or sell fixed assets to secure funds for R&D (Borisova & Brown, 2013; Liu et al., 2021). When resource constraints are severe and cannot be effectively circumvented, R&D investments will need to be adjusted despite the fact that such an action may not be entirely consistent with the initial plan for innovation outcome.

The third is R&D manipulation for earnings management. Researchers have found that earnings management is not conducive to firms' long-term performance (Graham, Harvey, & Rajgopal, 2005; Cohen et al., 2008). Firms' earnings management includes accrual earnings management and real earnings management. Roychowdhury (2006) points out that R&D expenditure is an important way to carry out real earnings management. Managers with short horizons may achieve their income goals by adjusting R&D expenditure for earnings purposes. As a result, the abnormal volatility of R&D expenditure may be due to R&D manipulation. He and Tian (2013) find that management presents short-sighted behaviors under great market pressure and may reduce innovation input to improve short-term performance as well as to meet analyst forecasts. In China, listed firms especially hope to avoid being ST or *ST-listed due to financial losses in consecutive years.[1] The volatility of R&D expenditure may also consist of R&D manipulation by firms to obtain certain qualification and tax incentives (Berger, 1993). Yang and Rui (2020) and Liu et al. (2023) find that to meet industrial policies, many Chinese firms inflate their R&D investments to meet the recognition standards as "high-tech firms", although the action may not be necessarily conducive to innovation. Some firms even carry out "tactical innovation" driven by China's industrial policies (Li & Zheng, 2016), resulting in a "patent bubble". Thus, earnings management and R&D manipulation motivations should be considered in the relationship between R&D management and technological innovation performance in the context of the current policy environment.

Our research makes the following marginal contributions. First, in contrast to prior studies on technological innovation that focus more on the roles of macro policy instruments and environment, such as government subsidies (Xu et al., 2023), R&D tax credits, legal protection for intellectual property, financial market rules (Brown et al., 2017), and capital-account liberalization (Bose et al., 2020), our study emphasizes the effect of corporate R&D dynamic inputs on different innovation outputs from the micro perspective of corporate behavior and motives. This study precisely reveals the corporate R&D decision process under different resource restraints, whereas existing studies on the roles of macro policy instruments and environment mainly discuss resource conditions for innovation. Therefore, our study contributes to the literature by complementing the resource-based mechanism of R&D management strategies.

Second, this study emphasizes the multi-period dynamic R&D expenditure adjustment of the Chinese listed firms. Different from the previous theory of proactive R&D management (Mudambi & Swift, 2011), it recognizes and focuses on the multiple realistic motivations of R&D management and classifies R&D management into strategically proactive intervention, resource-constrained passive adjustment, and R&D manipulation for earnings purposes from the firm level financial resource constraints and earnings

[1] According to the *Rules Governing the Listing of Stocks on Shanghai Stock Exchange*, listed companies that have suffered losses for certain consecutive years will be labeled "ST" or "*ST-listed", that is, stocks subject to special treatments for other risk warnings or delisting risk warning.

perspectives. In doing so, this study makes a distinctive contribution to the literature as few studies have paid attention to why firm R&D activities may be subject to different kinds of financial constraints as well as the need to balance the current earnings requirement with R&D investments. It is found that the dynamic adjustment of R&D investment under different motivations has varying effects on technological innovation performance.

Third, our study contributes to the resource-based view of ambidextrous innovation (Hughes et al., 2010; Wang et al., 2021) by providing novel evidence of organizational R&D jumps and proposing a new motive: earnings management.

Furthermore, to the best of our knowledge, this study is the first to demonstrate the asymmetric effects of the positive and negative volatilities of R&D management on ambidextrous innovation, which have been ignored in prior studies (Mudambi and Swift, 2011, 2014; Swift, 2016). It is found that positive volatility plays a more significant promoting role than negative volatility. Comparing the output difficulty and efficiency of exploration and exploitation, this paper provides evidence for strong innovation tendencies of firms on exploration instead of exploitation in an ambidextrous innovation strategy. Although it is easier to obtain output in exploitation innovation, firms pay more attention to exploration which brings about higher investment efficiency than exploitation. This result is striking as it may have important policy implications as far as innovation efficiency is concerned. It also constitutes an additional contribution of this paper to the literature.

The remainder of the paper is arranged as follows. Section 2 presents the theoretical analysis and research hypotheses. Section 3 describes the empirical specifications and data. Section 4 presents empirical results. Section 5 discusses the asymmetric effects. Section 6 is a robustness test that controls for the 2008 financial crisis. Section 7 concludes with policy implications.

2. Theoretical analysis and hypotheses

2.1. R&D investment management and ambidextrous technological innovation

According to the ambidextrous innovation theory (Dewar and Dutton, 1986; March, 1991), firm technological innovation activities can be classified into exploitation and exploration. Exploitation is an improved form of innovation based on existing knowledge and capabilities in a particular field, the emphasis of which is on improving existing innovations and products; exploration is a type of innovation that is more extensive and radical, aiming at entering a new field which is relatively unknown by others and thus producing breakthrough and high quality results (He & Wong, 2004; Hughes et al., 2010; Kahn & Candi, 2021; Wang et al., 2021; Xie & Gao, 2018). Firms are often faced with an intermittently balanced external environment where relative stability is interspersed with extreme changes, so they must practice both exploration and exploitation to survive and develop (Mudambi & Swift, 2011). They should not only use existing achievements to realize exploitation in a stable stage of technological development, but also break through the existing technology through exploration-oriented R&D activities in a turbulent and uncertain technological environment. It turns out that overemphasizing either the exploratory or exploitation approach may not always benefit a firm (Wang & Tsai, 2017; Wong et al., 2017; Zhang et al., 2020). Enterprises can achieve superior performance if they strike a balance between exploiting existing competences and exploring new opportunities (Buccieri et al., 2020; Harmancioglu et al., 2020; Martin et al., 2017). If firms switch between exploitation and exploration innovations, their R&D investments may become relatively unstable (Di Masi et al., 2003; Mudambi and Swift, 2011, 2014). When the business environment changes, to maintain their competitive advantages, firms may need to carry out proactive R&D investment management through switching their efforts between exploitation- and exploration-oriented R&D activities (Mavroudi et al., 2020). Therefore, under the premise that the volatility of R&D expenditure is regarded as firm strategic and proactive R&D management, the dynamic adjustment of R&D investment will stimulate innovation activities and enhance ambidextrous technological innovation performance.

It should be noted that the transition between exploitation and exploration may lead to higher risks (Anderson & Tushman, 2001; Benner & Tushman, 2003). This is because performance improvement due to proactive R&D management may also result in a dangerous leap, raising the probability of firm failure (Swift, 2016). Exploration is a fundamental and cutting-edge type of innovation, which is riskier than exploitation (Benner & Tushman, 2003) and may make enterprises fall into a failure trap (Lin & Chang, 2015). Firms may face more uncertainty and need to pay excessive conversion costs in switching between the two different types of innovation activities. However, in accordance with the risk-return trade-off, the higher risks that proactive R&D management incurs could also bring about higher returns. R&D transition in ambidextrous innovation will produce a portfolio of new technologies that helps firms to better adapt to the future industrial development trends, form stronger future competitive advantages (Hughes et al., 2010; Martin et al., 2017), and thus seize greater future values in return. Therefore, proactive firms are more willing to take high risks of R&D adjustment from ambidextrous innovation to pursue higher returns and competitive innovation portfolios. Based on this discussion, the following hypothesis is presented.

H1. The dynamic adjustment of firm R&D investment promotes the performance of ambidextrous technological innovation.

2.2. R&D investment management and ambidextrous innovation under different motivations

2.2.1. Financial resource constraints

The differences in firm resource endowments may lead to different types of R&D investment management. Consequently, R&D dynamic adjustment shows two different states: strategically proactive intervention and resource-constrained passive adjustment.

The resource-based theory indicates that the relationship between R&D investment and its output is affected by firm resource characteristics. Both exploration and exploitation require management attention and the effective allocation of limited resources

(March, 1991; Harmancioglu et al., 2020). R&D investment has high irreversibility and adjustment costs (Bond & Meghir, 1994; Cooper & Haltiwanger, 2006; Brown and Petersen, 2011), requiring great and continuous financial support. As R&D has a long investment cycle, high risk, and uncertainty, sufficient financial resources are important for firm level innovation processes. However, the implementation and adjustment of technological innovation strategies may cause competition for resources. Knowledge and human capital requirements differ greatly between exploitation and exploration. In addition, the demands for financing between the two are also different. Managers may take the initiative to make dynamic R&D investment, as some empirical studies showing that the economic environment and corporate characteristics of firms can seriously affect management enthusiasm for innovation investment, such as environmental dynamism (Buccieri et al., 2020) and corporate financial constraints (He & Tian, 2013). Therefore, firms with different financial resource characteristics have different R&D dynamic adjustment motivations, and the efficiency and benefits of their innovation strategy adjustment vary distinctively.

When firms make strategically proactive interventions, they should flexibly allocate relevant resource inputs, especially when limited resources must be switched from exploitation to exploration. Due to high risk and technical complexity of exploration, the shift from exploitation to exploration will make it uncertain to improve the R&D outcome, causing earnings reduction and aggravating information asymmetry between firms and external investors. The above reasons will lead to exploration facing more serious external financing constraints. Therefore, exploration is more likely to rely on internal finance which mainly comes from operating cash flow with high uncertainty. Firms with sufficient internal financial resources can flexibly and actively intervene in R&D according to their technological innovation goals. Therefore, the volatility of these firms' R&D expenditure reflects their proactive R&D management towards strategic competition and conforms to the adjustment trend of their ambidextrous innovation strategy.

For firms with insufficient financial resources, the volatility of R&D investment is more likely to take the form of passive adjustments because of capital constraints. When they find outstanding technological innovation opportunities and want to make innovation strategy adjustments, lack of financing may force them to abandon some desirable innovation projects. Due to high adjustment and sunk costs of R&D activities, continuous capital investment is imperative. However, when resource constraints are overwhelming and cannot be effectively circumvented, R&D investment needs to undergo the so-called passive adjustments. This can result in insufficient R&D investments. By forgoing some potentially beneficial R&D projects, unfortunately, firms will lose some valuable market opportunities in the long term. This passive adjustment may also detriment R&D momentum and continuity, incurring investment adjustment costs and reducing the efficiency and benefit of technological innovation. Therefore, R&D passive adjustment constrained by financial resource endowment is not conducive to the improvement of ambidextrous technological innovation. Based on this discussion, the following hypothesis is presented.

H2. R&D adjustments of firms with sufficient internal financial resources can significantly improve the performance of ambidextrous technological innovation, while those of firms with insufficient financial resources cannot.

2.2.2. Earnings management motivation

Organizational learning highlights short-sighted behaviors of ignoring long-term benefits and placing high value on short-term return (Levinthal & March 1993). Although Mudambi and Swift (2011) regard the volatility of R&D expenditure as the active adjustment of technological innovation strategy, this volatility may also be a manipulation motivated by earnings purposes. Managers may conduct earnings management to meet financial reporting objectives and personal interests (Roychowdhury, 2006). One common method is to adjust R&D expenditure to achieve the purpose of whitewashing financial statements. He and Tian (2013) find that greater market pressure would exacerbate managerial myopia under the attention of analysts. Therefore, to meet analyst forecasts of short-term performance, firms may opt to reduce their innovation investment to improve short-term profits, which inevitably suppresses innovation efforts. In China, financial losses of a listed firm for consecutive years will result in being ST or *ST-listed, leading to a sharp crash in stock prices, a strict limit on daily price variations, and stringent financial statement auditing (Lin & Zheng, 2016). To avoid this situation, firms may conduct earnings management and R&D manipulation. In addition, to lower the risk of performance

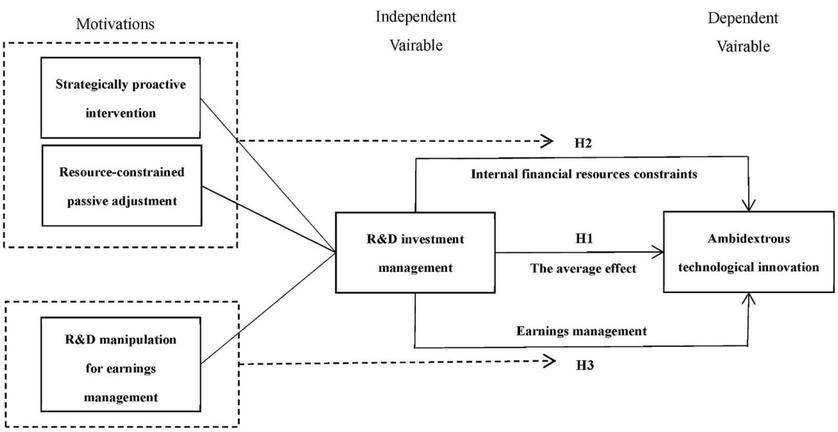

Fig. 1. R&D investment management and ambidextrous technological innovation.

volatility, managers may also consider cutting R&D expenditure when making investment decisions (Swift, 2016). If R&D investment adjustment is motivated by earnings purposes, voluntarily or involuntarily, it will not have a significant impact on technological innovation, because it only changes R&D expenditure in the statements, rather than presenting a strategic shift in technological innovation investment. Based on this discussion, the following hypothesis is presented.

H3. R&D adjustments with strong earnings management motivations have no significant effect on ambidextrous technological innovation performance, in contrast to firms with weak motivations.

The above mechanism analysis and theoretical assumptions are shown in Fig. 1.

3. Research design

3.1. Variables

3.1.1. R&D investment management

The independent variable is R&D investment management, denoted as *RD-management*. Mudambi and Swift (2011) propose that the volatility of R&D expenditure can be regarded as a visual proxy of firm forward-looking R&D management, so we construct the time series equation of R&D expenditure (*RDexp*) following their work as shown in Eq. (1).

$$RD\ exp_{i,t} = A_{0i} + A_{1i}t + \varepsilon_i \tag{1}$$

where *t* is time and *i* is firm. The residual of the trend line is actual R&D expenditure minus the trend value of R&D expenditure, namely ε_i. The volatility range of R&D expenditure is the absolute value of the residual. If the absolute value of a firm in the current year is in the first quartile of the absolute value during its sample period, *RD-management* is 1, which means that the firm intervenes in R&D investment in that year. Otherwise, it is 0, meaning that the firm does not make significant R&D adjustments in that year. This dummy variable reflects R&D investment management.

3.1.2. Ambidextrous technological innovation performance

The dependent variable, ambidextrous technological innovation performance, includes three different types of measurements: ambidextrous innovation patent portfolio, cutting-edge innovation possibility and technological innovation diversification. In previous studies, common proxies of innovation performance include R&D investment, patent number, patent citation, and new product announcement (Hagedoorn & Cloodt, 2003). Based on the ambidextrous innovation theory, we focus on different patent categories, patent citation and the entropy index of firm patent group diversification.

Firstly, the patent numbers in different categories are used to measure ambidextrous innovation patent portfolio. Invention patents among all Chinese patent categories (i.e., invention, utility model, and design) can represent firm core technological innovation capabilities due to their stronger technological breakthroughs, higher levels of innovation, and provide greater firm values, so it can be used to represent exploration innovation to some extent. Non-invention patent (utility model patent or design patent) is mainly tactical innovation which can be defined as exploitation innovation.[2] Since patent application year is closer to technological innovation date and can directly reflect firm innovation results, the number of patent applications is used to measure technological innovation output. In an ambidextrous innovation portfolio, the natural logarithm of the number of invention patent applications plus 1, namely *Ln*(*Patents*1+1), is to represent exploration innovation output, and the logarithm of the sum of utility model and design applications plus 1, namely *Ln*(*Patents*2+1), is to measure exploitation innovation output.

Secondly, patent citations are used to measure the possibility of cutting-edge innovation, termed as *High-citation*. Generally, when a firm develops patents that attract more attention and are more cited, the firm is considered to have implemented effective ambidextrous innovation and achieved more cutting-edge exploration innovation output. Therefore, if a firm has highly cited patents, it is more likely to obtain cutting-edge innovation results. The calculation of *High-citation* is as follows. The cumulative citation number of each patent for five consecutive years is calculated from the date of application. All patents are then sorted according to their cumulative numbers of citations. The patents ranked in the top 20% are defined as high-cited patents, otherwise they are defined as low-cited ones. If there is one or more high-cited patents applied by a firm in a certain year, it indicates that the firm obtains cutting-edge innovation in that year so that the variable *High-citation* takes the value of 1, and 0 otherwise.

Thirdly, the patent diversification entropy index is used to measure technological innovation diversification. Ambidextrous innovation also stimulates more exploration in new fields, thus causing the diversification of technological innovation. Mudambi and Swift (2011) use the entropy index to measure organizational diversification. Chen and Chang (2012) also use it to measure the diversification of the technological knowledge system. Based on these studies, we construct the patent diversification entropy index to measure the diversification of technological innovation.

$$PatentEI_{j,t} = \sum_{j=1}^{n} Q_{j,t} \times \mathrm{Ln}\left(1 / Q_{j,t}\right) \tag{2}$$

[2] *Patent Law of the People's Republic of China* classifies patents into invention, utility model and design. Invention patent refers to new technical solutions for products, methods, or technology that have the highest technical content and the strongest breakthrough among the three patents.

where $Q_{j,\,t}$ is the proportion of *j* patent group in the total patents of a firm in year *t*, and *n* is the number of all patent groups. China classifies patents in accordance with International Patent Classification, and the classification number includes section, class, subclass, main group, or group. We use the group symbol to classify patents.

3.1.3. R&D management motivation

We employ group regressions to compare the effect of R&D management on ambidextrous innovation performance under three different motivations.

Based on internal financial sources, we distinguish between strategically proactive interventions and resource-constrained passive adjustments of R&D, and then make regressions in groups with these two motivations respectively. Firms with abundant internal financial resources are more able to actively intervene in R&D activities, while the volatility of R&D expenditures for firms with insufficient resources could be a consequence of passive adjustment. As R&D relies more on internal financial support that mainly comes from operating cash flow, we first use net operating cash flow to measure internal financial resources. When net operating cash flow is greater than 0, internal cash flow is relatively more abundant for proactive R&D investment intervention. Otherwise, cash flow is less abundant so that R&D investment needs to be adjusted passively. We further consider the combined resource status of net operating cash flow and cash holdings because firms may sometimes use internal cash reserves (Pinkowitz & Williamson, 2001; Brown and Petersen, 2011) to support R&D investment. In this design, when net operating cash flow is less than 0 and cash holding is less than the industry median level, internal resources are regarded as being insufficient and hence R&D expenditure is likely to be adjusted passively. Otherwise, internal resources are relatively more abundant so that firms are more likely to actively invest in R&D.

The third R&D management motivation is for earnings management. Existing literature asserts that low-profit firms with *ROA* (return on assets) or $\triangle ROA$ (the change in return on assets) between (0, 0.01) have stronger earnings management motivations (Burgstahler & Dichev, 1997; Jacob & Jorgensen, 2007). Therefore, if a firm has *ROA* or $\triangle ROA$ between (0, 0.01), it may be more likely to have a strong earnings management motivation. In other words, if a firm is less profitable, it may tend to manipulate the level of R&D expenditure to demonstrate that it has better earnings performance. As a result, if firms have *ROA* or $\triangle ROA$ out of the (0, 0.01) range, they will have a weaker motivation of earnings management compared to those whose *ROA* or $\triangle ROA$ falling within the (0, 0.01) range. Then we make regressions in groups with strong and weak motivations of earnings management respectively and compare the results.

3.1.4. Control variables

The control variables include: *Size*, the natural logarithm of operating income; *ROA*, the rate of return on total assets, controlling profitability; *Cash,* cash reserves; *Capital,* capital expenditure; *Leverage,* debt level; *Age,* firm age; *TobinQ*, controlling growth opportunity; and *HoldersRate,* the shareholding proportion of the top ten shareholders, controlling ownership concentration which corresponds to the agency problem (Jackie et al., 2010).

3.2. Model

The basic definition of the empirical model is shown in Eq. (3) to test the impact of R&D investment adjustment on ambidextrous technological innovation performance.

$$Innovation_{i,t} = \alpha_0 + \alpha_1 RD - management_{i,t-1} + \alpha_2 Control_{i,t-1} + \sum Year + \sum Industry + \varepsilon_{i,t} \tag{3}$$

where ambidextrous innovation performance ($Innovation_{i,t}$) can be represented by *Ln*(*Patents*1+1), *Ln*(*Patents*2+1), *High-citation* or *PatentEI.* Since *High-citation* is a binary variable, logit regression is performed when it is used as the explained variable.

Control represents a set of control variables. $\sum$ *Industry* controls the industry effect, $\sum$ *Year* the year effect, $\varepsilon_{i,t}$ an error term.

To verify hypotheses 2 and 3, similar regressions are conducted using group subsamples based on internal financial resources and earnings management. The separate regression results are compared to examine how R&D investment management may have different impacts on ambidextrous innovation performance. The specific definitions and calculations of the variables are shown in Appendix 1.

3.3. Sample and data

The A-share listed firms on the Shanghai and Shenzhen Stock Exchanges during 2007–2019 are used as a large panel dataset to run the empirical models and verify the three hypotheses discussed previously. The data starts from 2007 because the accounting standards clarifying R&D investments were first issued in China in 2006 and enforced in 2007. Before the data are used for regression, a strict procession procedure is applied for cleaning purposes. More specifically, the following firms/observations are removed: 1) financial and real estate firms; 2) ST and *ST listed firms during the sample period; 3) firms with less than five annual R&D observations; and 4) firms with missing data. To eliminate the influence of outliers, all continuous variables are winsorized at their 1st and 99th percentiles. Finally, 1236 sample firms with 8890 unbalanced panel data were obtained. All the financial data are collected from the *China Stock Market & Accounting Research Database* and all the patent data from the *Chinese Research Data Services Platform* and *China Center for Economic Research.*

Table 1 lists the descriptive statistics of the relevant variables. About 21 percent of the sample firms/observations have significant R&D investments. The average exploration innovation output is 2.19 with a standard deviation of 1.47. The average exploitation innovation output is 2.12 with a standard deviation of 1.61. These two variables have little difference in the above statistics, indicating that firms engage in ambidextrous innovation to a certain extent, but the standard deviation and the gap between the extreme values manifest large differences between firms/years in the dataset. The average *High-citation* is 0.40 with a standard deviation of 0.49, indicating that about 60 percent of the sample firms/years have not developed highly cited patents, implying that cutting-edge innovation outputs are not strong, suggesting that the ambidextrous innovation activities have large room for improvement in the relevant listed firms. The average patent entropy index is 1.59 with a standard deviation of 0.85, implying that there are great differences in technological innovation diversification between firms/years in the sample.

4. Empirical results

4.1. Effect of R&D investment management on ambidextrous innovation

Eq. (3) is estimated using the entire sample and the results are reported in Table 2. Different columns represent similar regression results with different definitions of the dependent variables. The dependent variables in the first to the fourth columns are respectively invention patent applications (exploration innovation output), non-invention patent applications (exploitation innovation output), cutting-edge innovation possibility (*High-citation*) and the patent entropy index.

The estimated coefficient of R&D management on exploration innovation output is 0.080 and is significant at the 1% level, indicating that R&D intervention results in an increase in exploration innovation output, equivalent to 5.44% of its standard deviation. The coefficient on exploitation innovation output is 0.089 and is significant at the 1% level, indicating that R&D intervention can also lead to an increase in exploitation innovation, equivalent to 5.53% of its standard deviation. Both estimated coefficients imply that R&D investment management significantly promotes ambidextrous innovation portfolio in different patent categories. The coefficient of R&D management on *High-citation* is 0.175 and is significant at the 5% level, indicating that R&D intervention leads to an increased probability of 17.5% for cutting-edge innovations. The coefficient of R&D management on patent entropy index is 0.040 and is significant at the 5% level, indicating that R&D expenditure adjustments can increase patent diversification by 4.70% of its standard deviation. All the results in this table verify the first hypothesis presented earlier in the paper.

Moreover, the estimated coefficient of R&D investment management on exploitation innovation output is higher than that on exploration innovation, indicating that it is easier to obtain patents in exploitation than in exploration when firms intervene in R&D expenditure adopting an ambidextrous innovation strategy.

In a word, on average, the dynamic adjustment of R&D investment stimulates innovation activities and enhances ambidextrous technological innovation performance. To pursue competitive innovation portfolios, proactive firms are more inclined to take high risks of R&D adjustment from ambidextrous innovation.

4.2. R&D investment management and ambidextrous innovation under different motivations

4.2.1. R&D investment management under resource constraints

To distinguish strategically proactive intervention and resource-constrained passive adjustment, R&D management motivation is identified based on the characteristics of internal financial resources, dividing the whole sample into two groups with sufficient internal resources and insufficient internal resources. The former corresponds to strategically proactive interventions, and the latter is the passive adjustment under resource constraints. The regression results are reported in Table 3. The sample in Panel A is grouped on net operating cash flow and that in Panel B is grouped on combined resources of net operating cash flow and cash holdings.

Columns (1)–(4) in Panel A show that the R&D investment management in firms with insufficient internal cash flow has little impact on ambidextrous innovation patent portfolio, cutting-edge innovation possibility and patent entropy index; the coefficients of *RD-management* are insignificant. This may be because R&D passive adjustment cannot improve the efficiency and benefits of

Table 1
Descriptive statistics.

Variable	N	Minimum	Maximum	Mean	Standard deviation
RD-management	8890	0.00	1.00	0.21	0.41
Ln(*Patents*1+1)	8890	0.00	6.15	2.19	1.47
Ln(*Patents*2+1)	8890	0.00	6.14	2.12	1.61
High-citation	4491	0.00	1.00	0.40	0.49
PatentEI	8890	0.00	4.11	1.59	0.85
Cash	8890	0.02	0.76	0.22	0.16
Size	8890	19.97	26.21	22.12	1.26
Capital	8890	0.00	0.22	0.06	0.05
Leverage	8890	0.04	0.80	0.37	0.19
ROA	8890	−0.06	0.20	0.05	0.04
Age	8890	3.00	28.00	14.75	5.49
TobinQ	8890	0.91	7.65	2.13	1.23
HoldersRate	8890	0.28	0.91	0.60	0.14

Note: The calculation of *High-citation* requires at least five years of data after patent application, so the sample interval of this variable is from 2007 to 2015, and the sample size is less than other variables.

Table 2
R&D investment management and ambidextrous technological innovation.

	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln* (*Patents*1+1) (1)	Exploitation innovation *Ln* (*Patents*2+1) (2)	*High-citation*(3)	*PatentEI*(4)
$RD\text{-}management_{i,t\text{-}1}$	0.080***	0.089***	0.175**	0.040**
	(2.64)	(2.84)	(2.15)	(2.13)
$ROA_{i,t\text{-}1}$	1.536***	2.364***	2.999***	1.157***
	(4.21)	(6.27)	(2.82)	(5.26)
$Cash_{i,t\text{-}1}$	0.133	−0.066	−0.254	0.207***
	(1.25)	(-0.59)	(-0.94)	(3.22)
$Capital_{i,t\text{-}1}$	0.741**	0.541*	−0.113	0.530***
	(2.45)	(1.70)	(-0.16)	(2.83)
$Leverage_{i,t\text{-}1}$	0.052	0.264**	−0.109	0.093
	(0.51)	(2.54)	(-0.38)	(1.52)
$Size_{i,t\text{-}1}$	0.679***	0.667***	0.683***	0.190***
	(40.66)	(40.24)	(14.70)	(17.84)
$TobinQ_{i,t\text{-}1}$	0.060***	0.027*	0.062	0.015*
	(4.31)	(1.88)	(1.38)	(1.76)
$Age_{i,t\text{-}1}$	−0.001	−0.005	0.013*	0.004**
	(-0.19)	(-1.62)	(1.75)	(2.14)
$HoldersRate_{i,t\text{-}1}$	−0.325***	−0.418***	−0.202	−0.259***
	(-3.24)	(-4.10)	(-0.73)	(-4.34)
Constant	−14.169***	−12.214***	−15.367***	−4.257***
	(-34.82)	(-29.17)	(-13.21)	(-16.21)
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Observations	8890	8890	4491	8890
R-squared	0.377	0.431	0.106	0.312

Note: The dependent variables in columns (1)–(4) are *Ln*(*Patents*1+1), *Ln*(*Patents*2+1), *High-citation* and *PatentEI*, respectively. The calculation of *High-citation* requires at least five years of data after patent application, so the sample interval of this variable is from 2007 to 2015, and the sample size is less than other variables.
The z-values are in parentheses of column (3), and the t-values are in parentheses of other columns.
*$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

technological innovation under resource constraints. This is like the results of firms with insufficient internal resources portfolios in columns (1)–(4) of Panel B.

Columns (5), (6) and (8) in Panel A demonstrate that R&D investment management in firms with sufficient internal cash flow is a strategically proactive intervention and can flexibly and actively intervene in R&D investment to have a significantly positive effect on ambidextrous innovation with respect to the patent portfolios and the patent entropy index. The estimated coefficient on exploration innovation output is 0.074, that on exploitation innovation output 0.085, and that on the patent entropy index 0.047. All the estimated coefficients are significantly positive at the 5% level. The results are not dissimilar to those for firms with sufficient internal resources portfolios in columns (5), (6) and (8) of Panel B.

As shown in column (7) in Panel A, R&D investment management in firms with sufficient internal cash flow appears to have insignificant impact on cutting-edge innovation possibility. However, the results in column (7) of Panel B indicate that R&D investment management for firms with sufficient internal resources portfolios is found to have a significantly positive effect on cutting-edge innovation possibility. The estimated coefficient of *RD-management* is 0.157, which is significant at the 10% level. Overall, R&D investment management is found to have facilitated firms with sufficient internal resources to attain more cutting-edge innovation.

The above results prove that firms with abundant internal financial resources are more likely to actively manage R&D investment in line with their innovation strategy. The promotion effect on ambidextrous technological innovation is greater and more obvious than that of the passive adjustments for firms lacking financial resources. These research findings verify hypothesis 2 proposed earlier in this paper.

In short, the R&D volatility of firms with sufficient financial resources reflects their proactive R&D management toward strategic competition and conforms to the adjustment trend of their ambidextrous innovation strategy. However, passive R&D adjustment constrained by financial resource endowment is not conducive to the improvement of ambidextrous technological innovation.

4.2.2. R&D investment management and earnings purposes

To verify hypothesis 3, the full sample is further divided into two sub-samples with strong and weak earnings management motivations based on whether *ROA* or $\triangle ROA$ is between (0,0.01). The regression results are reported in Table 4.

Columns (1)–(4) of the table demonstrate that R&D investment management has little effect on ambidextrous innovation patent portfolio, cutting-edge innovation possibility and patent entropy index for firms with a strong earnings management motivation; the coefficients of *RD-management* are insignificant. This may be because R&D expenditure manipulation in earnings management aims to meet financial reporting objectives or managers' personal interests, which is not a real change in R&D investment strategy and thus has

Table 3
The effect of R&D investment management on ambidextrous innovation under resource constraints.

Panel A: grouped by operating cash flow

	Resource-constrained passive adjustment (Operating cash flow<0)				Strategically proactive intervention (Operating cash flow>0)			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1)(1)	Exploitation innovation *Ln*(*Patents*2+1)(2)	*High-citation*(3)	*PatentEI*(4)	Exploration innovation *Ln*(*Patents*1+1)(5)	Exploitation innovation *Ln*(*Patents*2+1)(6)	*High-citation*(7)	*PatentEI* (8)
$RD\text{-}management_{i,t\text{-}1}$	0.082	0.095	0.295	0.005	0.074**	0.085**	0.144	0.047**
	(1.14)	(1.28)	(1.51)	(0.11)	(2.21)	(2.47)	(1.59)	(2.29)
$ROA_{i,t\text{-}1}$	0.734	0.789	1.952	1.211*	1.808***	2.765***	3.496***	1.156***
	(0.74)	(0.78)	(0.66)	(1.83)	(4.52)	(6.70)	(2.98)	(4.91)
$Cash_{i,t\text{-}1}$	0.139	−0.126	−0.735	0.330**	0.107	−0.074	−0.214	0.170**
	(0.55)	(-0.48)	(-1.04)	(2.25)	(0.90)	(-0.60)	(-0.71)	(2.37)
$Capital_{i,t\text{-}1}$	0.878	0.445	−1.333	0.229	0.737**	0.596*	0.323	0.576***
	(1.31)	(0.65)	(-0.76)	(0.49)	(2.16)	(1.66)	(0.40)	(2.80)
$Leverage_{i,t\text{-}1}$	−0.318	−0.040	−0.899	0.036	0.172	0.364***	0.103	0.113*
	(-1.28)	(-0.16)	(-1.27)	(0.24)	(1.50)	(3.12)	(0.32)	(1.66)
$Size_{i,t\text{-}1}$	0.669***	0.640***	0.736***	0.168***	0.671***	0.665***	0.680***	0.192***
	(16.06)	(15.57)	(5.97)	(5.88)	(36.44)	(36.28)	(13.21)	(16.45)
$TobinQ_{i,t\text{-}1}$	0.063*	0.035	0.161	0.024	0.055***	0.020	0.044	0.012
	(1.86)	(0.99)	(1.38)	(1.12)	(3.58)	(1.26)	(0.88)	(1.34)
$Age_{i,t\text{-}1}$	0.005	0.009	0.037**	0.002	−0.001	−0.007**	0.007	0.004*
	(0.86)	(1.30)	(2.08)	(0.35)	(-0.48)	(-2.16)	(0.86)	(1.90)
$HoldersRate_{i,t\text{-}1}$	−0.474*	−0.337	0.007	−0.548***	−0.278**	−0.413***	−0.262	−0.199***
	(-1.86)	(-1.36)	(0.01)	(-3.46)	(-2.54)	(-3.69)	(-0.85)	(-3.07)
Constant	−13.989***	−12.983***	−16.323***	−2.277***	−13.587***	−12.859***	−15.415***	−4.797***
	(-13.00)	(-12.08)	(-5.40)	(-3.63)	(-32.25)	(-30.28)	(-11.92)	(-18.37)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1537	1537	832	1537	7353	7353	3659	7353
R-squared	0.412	0.464	0.117	0.321	0.378	0.432	0.113	0.318

Panel B: grouped by the combination of operating cash flow and cash holding

(*continued on next page*)

Table 3 (*continued*)

Panel B: grouped by the combination of operating cash flow and cash holding

	Resource-constrained passive adjustment (Operating cash flow<0 and Cash holding < industry median)				Strategically proactive intervention (Other combinations)			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
	Resource-constrained passive adjustment (Operating cash flow<0 and Cash holding < industry median)				Strategically proactive intervention (Other combinations)			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
$RD\text{-}management_{i,t\text{-}1}$	0.064	0.085	0.341	−0.023	0.076**	0.086***	0.157*	0.047**
	(0.60)	(0.81)	(1.18)	(-0.35)	(2.41)	(2.63)	(1.83)	(2.40)
$ROA_{i,t\text{-}1}$	4.620***	4.005***	17.468***	2.115**	1.419***	2.364***	2.124*	1.092***
	(3.21)	(2.65)	(3.60)	(2.28)	(3.74)	(6.04)	(1.91)	(4.80)
$Cash_{i,t\text{-}1}$	0.258	0.344	−1.745	0.367	0.120	−0.069	−0.214	0.192***
	(0.50)	(0.65)	(-1.22)	(1.16)	(1.08)	(-0.60)	(-0.75)	(2.86)
$Capital_{i,t\text{-}1}$	1.565*	0.868	1.362	0.435	0.744**	0.594*	0.143	0.506**
	(1.78)	(0.93)	(0.58)	(0.74)	(2.28)	(1.73)	(0.18)	(2.53)
$Leverage_{i,t\text{-}1}$	0.022	0.300	0.478	0.186	0.126	0.322***	−0.058	0.087
	(0.07)	(0.90)	(0.51)	(0.95)	(1.16)	(2.91)	(-0.19)	(1.34)
$Size_{i,t\text{-}1}$	0.540***	0.512***	0.481***	0.159***	0.682***	0.674***	0.702***	0.194***
	(9.35)	(9.10)	(2.96)	(3.77)	(39.01)	(38.69)	(14.25)	(17.39)
$TobinQ_{i,t\text{-}1}$	0.014	−0.037	−0.218	0.029	0.063***	0.030**	0.081*	0.013
	(0.27)	(-0.67)	(-1.21)	(0.96)	(4.31)	(1.98)	(1.72)	(1.54)
$Age_{i,t\text{-}1}$	0.015*	0.021**	0.064**	−0.005	−0.002	−0.007**	0.009	0.004**
	(1.72)	(2.44)	(2.53)	(-0.87)	(-0.69)	(-2.34)	(1.07)	(2.43)
$HoldersRate_{i,t\text{-}1}$	−0.554	−0.271	−1.500	−0.527**	−0.326***	−0.450***	−0.158	−0.238***
	(-1.59)	(-0.79)	(-1.44)	(-2.53)	(-3.09)	(-4.19)	(-0.54)	(-3.80)
Constant	−11.889***	−11.689***	5.629	−2.692***	−13.733***	−12.937***	−16.098***	−4.776***
	(-9.74)	(-9.55)	(0.00)	(-2.96)	(-34.32)	(-31.99)	(-13.06)	(-19.18)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	878	878	473	878	8012	8012	4018	8012
R-squared	0.370	0.419	0.158	0.329	0.384	0.438	0.109	0.316

Note: Panel A is grouped based on net operating cash flow and columns, Panel B is grouped based on combined resources of net operating cash flow and cash holdings. The calculation of *High-citation* requires at least five years of data after patent application, so the sample interval of this variable is from 2007 to 2015, and the sample size is less than other variables.
The z-values are in parentheses of column (3) and column (7), and the t-values are in parentheses of other columns. *$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

Table 4
The effect of R&D investment management on ambidextrous innovation under earnings management motivation.

	Strong earnings management motivation				Weak earnings management motivation			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
$RD\text{-}management_{i,t\text{-}1}$	0.053	0.054	0.155	−0.005	0.089**	0.100***	0.174*	0.058***
	(0.97)	(0.96)	(0.95)	(-0.15)	(2.45)	(2.67)	(1.82)	(2.62)
$ROA_{i,t\text{-}1}$	2.125***	3.276***	3.216	1.046**	1.402***	2.138***	2.484**	1.179***
	(2.76)	(4.18)	(1.41)	(2.19)	(3.30)	(4.86)	(2.01)	(4.68)
$Cash_{i,t\text{-}1}$	0.231	−0.002	−0.414	0.227*	0.108	−0.078	−0.153	0.203***
	(1.15)	(-0.01)	(-0.75)	(1.82)	(0.86)	(-0.59)	(-0.48)	(2.69)
$Capital_{i,t\text{-}1}$	0.860	0.437	−0.314	0.387	0.761**	0.643*	0.212	0.610***
	(1.41)	(0.70)	(-0.22)	(1.03)	(2.15)	(1.72)	(0.25)	(2.78)
$Leverage_{i,t\text{-}1}$	−0.002	0.213	−0.844	0.130	0.070	0.271**	0.179	0.072
	(-0.01)	(1.13)	(-1.51)	(1.10)	(0.56)	(2.16)	(0.53)	(1.00)
$Size_{i,t\text{-}1}$	0.735***	0.712***	0.749***	0.199***	0.662***	0.654***	0.674***	0.186***
	(23.68)	(23.23)	(8.42)	(9.82)	(33.03)	(32.80)	(12.07)	(14.66)
$TobinQ_{i,t\text{-}1}$	0.113***	0.062**	−0.124	−0.002	0.050***	0.022	0.115**	0.022**
	(3.88)	(2.05)	(-1.20)	(-0.10)	(3.12)	(1.33)	(2.25)	(2.31)
$Age_{i,t\text{-}1}$	−0.004	−0.005	0.012	0.003	0.002	−0.004	0.016*	0.004*
	(-0.79)	(-0.92)	(0.80)	(0.99)	(0.46)	(-1.10)	(1.79)	(1.84)
$HoldersRate_{i,t\text{-}1}$	−0.356**	−0.408**	−0.205	−0.299***	−0.333***	−0.453***	−0.272	−0.238***
	(-2.01)	(-2.25)	(-0.40)	(-2.62)	(-2.73)	(-3.65)	(-0.82)	(-3.37)
Constant	−15.384***	−14.776***	−16.365***	−3.490***	−13.412***	−13.152***	−15.202***	−2.992***
	(-22.45)	(-21.39)	(-7.62)	(-6.08)	(-32.57)	(-32.08)	(-10.61)	(-11.22)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2599	2599	1270	2599	6291	6291	3221	6291
R-squared	0.429	0.483	0.115	0.339	0.365	0.420	0.111	0.307

Note: The sample is grouped based on whether *ROA* or $\triangle ROA$ are between (0,0.01). Firms with *ROA* or $\triangle ROA$ between (0,0.01) have strong earnings management motivations; otherwise, they have weak earnings management motivations. The calculation of *High-citation* requires at least five years of data after patent application, so the sample interval of this variable is from 2007 to 2015, and the sample size is less than other variables. The z-values are in parentheses of column (3) and column (7), and the t-values are in parentheses of other columns. *$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

little effect on technological innovation. Columns (5)–(8) show that R&D investment management plays a significant role in promoting ambidextrous innovation patent portfolio, cutting-edge innovation possibility and patent diversification for firms with weak earnings management motivations. The estimated coefficient on exploration innovation output is 0.089, which is significant at the 5% level; the coefficient on exploitation innovation is 0.100 and is significant at the 1% level; the coefficient on cutting-edge innovation possibility is 0.174 and is significant at the 10% level; the coefficient on patent entropy index is 0.058 and is significant at the 1% level.

This indicates that the volatility of R&D expenditure does not contribute to the improvement of ambidextrous technological innovation if R&D investment management is conducted for earnings management purposes, because it only changes R&D expenditure in the statements, rather than presenting a true strategic shift in technological innovation investment. Correspondingly, hypothesis 3 in this paper is verified.

5. Asymmetric effect of different intervention directions and R&D efficiency

The directions of R&D investment adjustment are identified to analyze the different effects of positive and negative volatilities of R&D expenditure on ambidextrous innovation. Eq. (3) is further run adding the dichotomous variables of R&D investment adjustment as shown in Eq. (4) following Kang et al. (2017).

$$Innovation_{i,t} = \alpha_0 + \alpha_1 Pvolatility_{i,t-1} + \alpha_2 Nvolatility_{i,t-1} + \alpha_3 Control_{i,t-1} + \sum Year + \sum Industry + \varepsilon_{i,t} \quad (4)$$

where R&D investment management is replaced by the volatility of R&D expenditure which is the residual obtained through the regression results based on Eq. (1). It is then decomposed into two parts: *Pvolatility* representing the positive volatility of R&D expenditure and *Nvolatility* representing the negative volatility of R&D expenditure. When $Volatility>0$, *Pvolatility* equals *Volatility*, and 0 otherwise. When $Volatility<0$, *Nvolatility* equals *Volatility*, and 0 otherwise. The control variables are the same as in Eq. (3).

The regression results are shown in Table 5. For exploration innovation output, the estimated coefficient of positive R&D volatility in column (1) is 7.989, and the estimated coefficient of negative volatility −6.241. Both estimated coefficients are significant at the 1% level. For exploitation innovation output, the estimated coefficient of positive volatility in column (2) is 5.703 and is significant at the 1% level, but the estimated coefficient of negative volatility is −2.611 and is insignificant. These results indicate that the effects of R&D expenditure positive and negative volatilities on ambidextrous innovation patents are asymmetric. Positive intervention can improve ambidextrous innovation, but negative volatility can only promote exploration innovation. This is because exploration is an activity

Table 5
Asymmetric effects of R&D investment management in different intervention directions on ambidextrous innovation.

	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)
$PVolatility_{i,t\text{-}1}$	7.989***	5.703***	11.508***	2.921***
	(5.01)	(3.52)	(3.28)	(2.84)
$NVolatility_{i,t\text{-}1}$	−6.241***	−2.611	−11.282***	−0.808
	(-3.95)	(-1.59)	(-3.10)	(-0.87)
$ROA_{i,t\text{-}1}$	1.855***	2.586***	3.562***	1.274***
	(4.98)	(6.74)	(3.29)	(5.74)
$Cash_{i,t\text{-}1}$	0.097	−0.090	−0.340	0.195***
	(0.91)	(-0.81)	(-1.25)	(3.03)
$Capital_{i,t\text{-}1}$	0.708**	0.503	−0.150	0.506***
	(2.34)	(1.58)	(-0.21)	(2.70)
$Leverage_{i,t\text{-}1}$	0.115	0.307***	−0.023	0.115*
	(1.10)	(2.91)	(-0.08)	(1.86)
$Size_{i,t\text{-}1}$	0.680***	0.667***	0.689***	0.190***
	(40.83)	(40.29)	(14.78)	(17.80)
$TobinQ_{i,t\text{-}1}$	0.052***	0.022	0.048	0.012
	(3.68)	(1.51)	(1.05)	(1.44)
$Age_{i,t\text{-}1}$	0.001	−0.004	0.015**	0.004**
	(0.27)	(-1.36)	(2.01)	(2.30)
$HoldersRate_{i,t\text{-}1}$	−0.316***	−0.413***	−0.176	−0.257***
	(-3.17)	(-4.06)	(-0.64)	(-4.31)
Constant	−14.283***	−12.272***	−15.604***	−4.281***
	(-34.99)	(-29.21)	(-13.35)	(-16.25)
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Observations	8890	8890	4491	8890
R-squared	0.379	0.431	0.108	0.312

Note: The dependent variables in columns (1)–(4) are *Ln*(*Patents*1+1), *Ln*(*Patents*2+1), *High-citation* and *PatentEI*, respectively. The calculation of *High-citation* requires at least five years of data after patent application, so the sample interval of this variable is from 2007 to 2015, and the sample size is less than other variables. The z-values are in parentheses of column (3), and the t-values are in parentheses of other columns.
*$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

that needs more flexible R&D management and more complex shifts in R&D, including more investments and strategic R&D expenditure adjustments. Both different directions of R&D management can improve exploration innovation. However, the effect of positive intervention is significantly greater than that of negative intervention.

Column (3) demonstrates that the effects of R&D expenditure positive and negative volatilities on cutting-edge innovation are less asymmetrical. The coefficient of positive R&D volatility is 11.508 and that of negative volatility −11.282, both of which are significant at the 1% level.

Obvious asymmetry can also be found in column (4) as the regression results show that positive adjustment of R&D expenditure on patent diversification has a more potent impact than that of negative adjustment. The estimated coefficient of positive volatility is 2.921 and is significant at the 1% level, but the estimated coefficient of negative volatility is insignificant.

The above-mentioned asymmetric effect may be caused in two ways. On the one hand, output is proportional to input, and positive adjustment leads to more R&D input, which is more conducive to innovative output. On the other hand, in the negative adjustment of R&D expenditure, some R&D expenditure downward adjustment may be due to earnings management, financial resource constraints, or risk aversion. The impact of such adjustments on R&D expenditure on ambidextrous innovation may reduce or even offset the positive effect of the strategically proactive adjustment of R&D expenditure on technological innovation performance.

In addition, comparing with the results in Table 2, the results in Table 5 show that the effect of R&D management on exploration innovation is greater than that on exploitation, suggesting that when firms implement ambidextrous innovation, they may pay more attention to exploration innovation so that R&D investment efficiency in exploration is higher, although it is easier to obtain output in exploitation.

6. Robustness test: controlling for the financial crisis of 2008

Some researchers have found that the global financial crisis of 2008 can affect innovation (Archibugi et al., 2013; Degryse et al., 2018; Nemlioglu and Mallick, 2017, 2021); therefore, this event may influence our results to some extent. We perform a robustness test to control for this crisis in this section. Regarding the 2008 global financial turmoil, it is commonly agreed that its effects on the Asian region, as well as other regions, began in September 2007 because of the appearance of the subprime problem and continued until 2009 (Driessen & Van Hemert, 2012; Yiu et al., 2010). Therefore, we set a dummy variable *Crisis* representing the financial crisis and add it into Eqs. (3) and (4) to observe the relationship between R&D investment management and ambidextrous innovation performance after controlling for the impact of the financial crisis. The period from 2007 to 2009 is defined as the period of the financial crisis (Yiu et al., 2010). During this period, the value of *Crisis* is 1; otherwise, it is 0.

The regression results are shown in Tables 6–9, which are consistent with those in Tables 2–5. This indicates that our study has controlled for the crisis's systematic impact by year- and industry-fixed effects. After further controlling for the crisis by adding its dummy, the results of this study are still robust.

7. Conclusions

This study takes the listed firms on the Chinese stock markets in 2007–2019 to examine the effect of R&D investment management on ambidextrous technological innovation performance. From the two dimensions of internal financial resource constraints and earnings management, R&D investment management is classified into three motivations: strategically proactive intervention, resource-constrained passive adjustment, and R&D manipulation for earnings purposes. We then analyze the effect of R&D investment adjustment on the patent portfolio of ambidextrous innovation, cutting-edge innovation possibility and patent diversification.

Our findings show that R&D investment management plays a significant role in promoting ambidextrous technological innovation, which varies under different motivations. Firms with ample internal financial resources have the ability and motivation to proactively

Table 6
R&D investment management and ambidextrous technological innovation: controlling for the financial crisis of 2008.

	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln(Patents1+1)* (1)	Exploitation innovation *Ln(Patents2+1)* (2)	*High-citation* (3)	*PatentEI* (4)
RD-management$_{i,t-1}$	0.080***	0.067**	0.175**	0.040**
	(2.64)	(2.12)	(2.14)	(2.13)
Crisis$_{i,t-1}$	−0.026	−0.036	0.142	−0.037
	(-0.17)	(-0.23)	(0.46)	(-0.45)
Constant	−14.169***	−10.701***	−15.361***	−3.131***
	(-34.82)	(-25.27)	(-13.81)	(-11.81)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Observations	8890	8890	4491	8890
R-squared	0.377	0.454	0.106	0.309

Note: The z-values are in parentheses of column (3), and the t-values are in parentheses of other columns.
*p < 0.10. **p < 0.05. ***p < 0.01.

Table 7
The effect of R&D investment management on ambidextrous innovation under resource constraints: controlling for the financial crisis of 2008.

Panel A:grouped by operating cash flow

	Resource-constrained passive adjustment (Operating cash flow<0)				Strategically proactive intervention (Operating cash flow>0)			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
$RD\text{-}management_{i,t\text{-}1}$	0.082	0.068	0.296	0.005	0.074**	0.068*	0.144	0.047**
	(1.13)	(0.91)	(1.51)	(0.11)	(2.21)	(1.94)	(1.57)	(2.29)
$Crisis_{i,t\text{-}1}$	0.104	−0.154	1.681**	0.010	−0.077	−0.048	−0.046	−0.036
	(0.42)	(-0.46)	(2.08)	(0.07)	(-0.45)	(-0.27)	(-0.13)	(-0.37)
Constant	−13.901***	−11.057***	−16.338***	−0.068	−13.718***	−11.436***	−15.417***	−4.424***
	(-15.73)	(-11.99)	(-5.23)	(-0.11)	(-29.07)	(-21.95)	(-12.62)	(-8.80)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1537	1537	832	1537	7353	7353	3659	7353
R-squared	0.412	0.481	0.121	0.321	0.378	0.457	0.113	0.315

Panel B: grouped by the combination of operating cash flow and cash holding

	Resource-constrained passive adjustment (Operating cash flow<0 and Cash holding < industry median)				Strategically proactive intervention (Other combinations)			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
$RD\text{-}management_{i,t\text{-}1}$	0.069	0.122	0.347	−0.025	0.076**	0.061*	0.157*	0.047**
	(0.65)	(1.20)	(1.20)	(-0.38)	(2.41)	(1.84)	(1.81)	(2.39)
$Crisis_{i,t\text{-}1}$	0.891**	1.085*	0.639	−0.340**	−0.022	−0.046	0.137	−0.027
	(2.47)	(1.90)	(0.61)	(-2.11)	(-0.14)	(-0.29)	(0.44)	(-0.32)
Constant	−12.685***	−9.168***	−10.390***	−2.150**	−13.728***	−11.450***	−16.093***	−4.339***
	(-10.45)	(-6.85)	(-2.82)	(-2.41)	(-34.23)	(-25.88)	(-13.75)	(-10.49)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	878	878	473	878	8012	8012	4018	8012
R-squared	0.371	0.453	0.158	0.329	0.384	0.460	0.109	0.313

Note: The z-values are in parentheses of columns (3) and (7), and the t-values are in parentheses of other columns. *$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

Table 8
The effect of R&D investment management on ambidextrous innovation under earnings management motivation: controlling for the financial crisis of 2008.

	Strong earnings management motivation				Weak earnings management motivation			
	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation *Ln*(*Patents*1+1) (1)	Exploitation innovation *Ln*(*Patents*2+1) (2)	*High-citation* (3)	*PatentEI* (4)	Exploration innovation *Ln*(*Patents*1+1) (5)	Exploitation innovation *Ln*(*Patents*2+1) (6)	*High-citation* (7)	*PatentEI* (8)
RD-management$_{i,t\text{-}1}$	0.055	0.065	0.152	−0.004	0.089**	0.064*	0.174*	0.058***
	(1.01)	(1.11)	(0.92)	(-0.12)	(2.45)	(1.69)	(1.80)	(2.61)
Crisis$_{i,t\text{-}1}$	−0.438	0.186	0.217	−0.173	0.132	−0.056	0.141	0.012
	(-1.45)	(0.54)	(0.34)	(-0.89)	(0.81)	(-0.33)	(0.40)	(0.14)
Constant	−14.997***	−11.990***	−16.361***	−1.425**	−13.603***	−10.403***	−15.192***	−2.742***
	(-21.93)	(-13.63)	(-8.03)	(-2.46)	(-27.56)	(-21.13)	(-11.08)	(-8.42)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2599	2599	1270	2599	6291	6291	3221	6291
R-squared	0.429	0.487	0.115	0.337	0.365	0.447	0.111	0.304

Note: The z-values are in parentheses of columns (3) and (7), and the t-values are in parentheses of other columns. *$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

Table 9
Asymmetric effects of R&D investment management in different intervention directions on ambidextrous innovation: controlling for the financial crisis of 2008.

	Ambidextrous innovation patent portfolio		Cutting-edge innovation possibility	Patent diversification
	Exploration innovation $Ln(Patents1+1)$ (1)	Exploitation innovation $Ln(Patents2+1)$ (2)	*High-citation* (3)	*PatentEI* (4)
$PVolatility_{i,t\text{-}1}$	7.992***	4.712***	11.464***	2.925***
	(5.01)	(3.05)	(3.27)	(2.85)
$NVolatility_{i,t\text{-}1}$	−6.237***	−3.625	−11.330***	−0.802
	(-3.94)	(-1.98)	(-3.03)	(-0.86)
$Crisis_{i,t\text{-}1}$	−0.023	−0.046	0.147	−0.039
	(-0.15)	(-0.30)	(0.48)	(-0.48)
Constant	−14.282***	−10.653***	−15.598***	−3.111***
	(-34.99)	(-25.27)	(-13.99)	(-11.77)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Observations	8890	8890	4491	8890
R-squared	0.379	0.454	0.108	0.310

Note: The z-values are in parentheses of column (3), and the t-values are in parentheses of other columns.
*$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

carry out strategic interventions on R&D investment. When adjusting their technological innovation strategies, they can flexibly implement matching financial strategies to support proactive R&D investment management. However, the R&D investment volatility of firms lacking internal financial resources may be passive adjustments under stress. Thereby, the R&D investment management of the former will significantly improve the performance of ambidextrous technological innovation.

The R&D investment adjustments in firms with strong earnings management motivations are caused by R&D manipulation and only change the R&D expenditure in financial statements, rather than through strategic shifts of technological innovation investment and virtually proactive R&D management. Therefore, R&D expenditure adjustments of firms with strong earnings management motivations have no significant effect on ambidextrous technological innovation performance, in contrast to firms with weak earnings management motivations.

After distinguishing and comparing the asymmetric effects of the positive and negative volatilities of R&D management on ambidextrous innovation, we find that positive volatility plays a more significant promoting role than negative volatility. In implementing ambidextrous innovation strategies, firms pay more attention to exploration innovation and thus their investment efficiency is higher, although exploitation enables the obtainment of research and development outputs more easily.

To control for the potential impact of the global financial crisis, we conduct a robustness test by introducing a dummy variable for the financial crisis in the regressions, which also supports the results of this study.

Our research enriches the literature in R&D investment management and has important theoretical implications for firm ambidextrous innovation decision-making practices.

From the perspective of firm innovation management, to maintain competitive advantages, managers should correctly identify technological innovation opportunities and the value of R&D investment projects and proactively carry out R&D interventions. They should adjust their innovation strategies in accordance with the market environment, evaluating and adjusting R&D investment decisions in a timely manner. At the same time, it is highly important that they focus on long-term development and avoid R&D manipulation caused by shortsightedness. In addition, firms should formulate financial strategies in line with innovation strategy according to their own financial resource endowments, improve their innovation efficiency and capabilities, realize the optimal allocation of financial resources in R&D investment, and thus strengthen their competitive advantages in the market.

From the perspective of external stimulation to innovation, firstly, the government should improve the R&D subsidy mechanism and tax preference regulations to enterprises in different R&D stages and of different natures, enriching their financial resources and encouraging their proactive R&D management. In addition, information disclosure should be normalized further and the supervision on R&D subsidy and tax preference should be reinforced to prevent R&D manipulation of firms for obtaining certain qualification and tax incentives or meeting financial reporting objectives.

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Appendix 1. Variable definitions

	Variable	Variable name	Specific definition
Independent variable	*RD-management*	R&D investment management	Dummy variable. If the absolute value of the residual in Eq. (1) is in the first quartile of the sample period, it is set to 1, indicating that a firm makes significant R&D investment interventions. Otherwise, it is set to 0, indicating that the firm does not make significant R&D investment adjustments.
Dependent variables	*Ln (Patents1+1)*	Exploration innovation output	Ln (number of invention patent applications + 1)
	Ln (Patents2+1)	Exploitation innovation output	Ln (number of utility model patent applications + number of design patent applications + 1)
	High-citation	Cutting-edge innovation possibility	Dummy variable. Sort the patents according to the number of citations accumulated for five consecutive years from the date of application. The patents ranked in the top 20% are defined as high-cited patents, otherwise as low-cited patents. If there is one or more high-cited patents applied by a company in certain year, *High-citation* is defined as 1, otherwise as 0.
	PatentEI	Patent diversification entropy index	$PatentEI_{j,t} = \sum_{j=1}^{n} Q_{j,t} \times \text{Ln}(1/Q_{j,t})$
Control variables	*Size*	Firm size	Ln (operating income)
	Cash	Cash holding	(Cash + financial assets held for trading)/total assets
	ROA	Net profit on assets	Net profit/total assets
	Capital	capital expenditure	Total capital expenditure/total assets
	Age	Firm age	The current year minus the firm establishment year
	Leverage	Financial leverage	Total liabilities/total assets
	TobinQ	Growth ability	Market value/total assets
	HoldersRate	Shareholding by top ten shareholders	Total shareholding ratio of the top ten shareholders
	RDexp	R&D investment	R&D expenditure/operating income

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