Stock option, contract elements design and corporate innovation output – an analyse based on risk-taking and performance-based incentives

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Abstract

Purpose – With the accelerated technological advancement, innovation has become a critical factor, which affects the core competitiveness of a company. However, studies about the relationship between internal stock option mechanisms and innovation productivity remain limited. Therefore, this paper aims to examine the impact of stock options and their elements design on innovation output from an internal mechanism perspective.

Design/methodology/approach – Using a sample of 302 stock option incentive plans announced and implemented between 2006 and 2016, this study uses the propensity score matching and difference-in-difference model to find out whether the implementation of stock options improves the innovation outputs of enterprises.

Findings – Based on the statistical analysis, it is concluded that: stock options can stimulate corporate innovation; a stock option may drive innovation outputs through two ways, performance-based incentives and risk-taking incentives, with the latter one playing a more dominant role and the risk-taking incentives of stock options, could be optimised when the non-executives granting proportion is larger, the granting range is limited, the incentive period is longer, the exercisable proportion is increasing, the price-to-strike ratio is lower and relatively loose performance assessment criteria are applied.

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Originality/value – The conclusion reached in the study may provide valuable information to listed firms in designing and implementing the stock option plans.

Keywords Stock option, Innovation output, Element design, Performance-based incentives, Risk-taking incentives

Paper type Research paper

1. Introduction

From 2010 onwards, Chinese economic development has entered into a new era featured by a changing of economic structure and the optimisation of industrial structure. It is aimed to transform the country's factor and investment-led economy to one driven by innovations. In this context, how to stimulate independent innovation amongst Chinese enterprises has become an important topic. Innovation activities significantly impact the risk and time distribution of corporate returns (Holmstro, 1989). They tend to have a higher failure rate than other production and operation activities but a much longer payback period. Therefore, enterprise innovation requires the design of compatible incentive mechanisms that tolerate short-term failure and rewards long-term success (Manso, 2011).

Equity incentive compensation contracts are convex and long-term oriented. This type of contract can motivate employees to undertake risks and attract and retain innovative talent within an organisation. This feature is consistent with the risk and long-term characteristics of innovation activities (Holmstro, 1989), and hence, is widely used as an important compensation tool for corporate innovation. As the implementation of *Measures for the Administration of Equity Incentives of Listed Companies (Trial)* (Hereinafter referred to as *Measures for the Administration*) in 2006, equity incentives have been widely leveraged by listed companies. The main incentive methods include stock options and restricted stocks. Amongst them, the stock option is asymmetric in rights and obligations. as well as incentives and punishments. Its convexity is also stronger than restricted stocks, making it more suitable to stimulate risk-taking behaviours (Manso, 2011; Guay, 1999; Murphy, 2003; Coles *et al.*, 2006; Low, 2009). However, the effectiveness of this incentive mechanism is closely related to the rational design of contract elements. In this paper, we summarised the main contract elements of 302 stock option incentive plans implemented by the Chinese listed companies over the period of 2006 to 2016, as shown in Table 1.

It can be seen from Table 1 that the stock options of China tend to focus more on providing incentives to non-executive directors. In our sample, 77.2% of the stock options are granted to non-executives, with 90.5% of the incentive targets is non-executives. In general, an average of 3.1% of the shares is granted as stock options, covering about 9.2% of the total employees. However, significant differences are identified amongst the different schemes implemented. Amongst them, the proportion of shares granted reaches an upper limit of 10% set by *Measures for the Administration*, with the largest granting range covering 62.2% of employees. The incentive period is typically five years in length and 48.7% of the plans are incremental exercises. Furthermore, the average premium for stock options granted for the year is 2.5%, with the maximum premium reaching 305.6%. It seems that firms are showing timing behaviours when granting stock options as the announcement at a low price level could lower the exercise price (Zhang and Xiao, 2012). Amongst the cases studied in our research, about 72.5% of the schemes set the performance assessment criteria higher than the performance level over the past three years.

As a result, one may conclude that the elements design of stock options in China is different from that of the US firms. In terms of the exercise proportion, the US companies generally adopt contingent-vesting, with a decreased proportion allowed for exercising, but

Table 1.
Statistics of stock option elements design from 2006 to 2016

Element design	Indicators	Mean	SD	Median	Minimum	Maximum	No. of samples
Incentive objectives	Number of stock options granted to non-executive/total number of stock options	0.772	0.212	0.826	0	1	302
	Number of non-executive granted/total number of granted	0.905	0.170	0.956	0	1	302
Granting range	Total number of shares granted/total number of shares of the company	0.031	0.022	0.027	0.014	0.100	302
	Total number of employees granted/total number of employees in the company	0.092	0.101	0.064	0.001	0.622	302
Incentive period	Years of incentive period	4.856	1.237	5	3	10	302
Exercise proportion	1 when the exercise proportion is increasing, 0 otherwise	0.487	0.501	1	0	1	300
Price-to-strike ratio	Opening price of the stock in the year of grant/exercise price	1.025	0.303	0.994	0.350	3.056	302
Performance assessment criteria	Perf is 1 if it is greater than the value of any of the previous 3 years or greater than the mean of the previous 3 years, otherwise, it is 0	0.725	0.447	1	0	1	302

Source: Draft of the stock option incentive plan of listed companies disclosed by CNINF

for Chinese companies, accelerated-vesting is more widely used to allow for increased exercising proportions (Bettis *et al.*, 2010; Bettis *et al.*, 2018). As for the exercise price, the law of the US allows companies to reprice out-of-the-money stock options (Carter and Lynch, 2004) but the government banned such practice. As for performance assessment criteria, the US firms can set up assessment criteria voluntarily but firms in China are required to set performance assessment criteria against one's exercise rights to encourage good performance (Bettis *et al.*, 2018). All these differences have made the stock options offering unique amongst Chinese firms. However, whether such a design is more effective in stimulating the risk-taking incentives of the stock options amongst Chinese listed firms? This is the question this research aims to investigate.

Many existing studies have confirmed the positive impact of stock options on firms' innovation outputs (Wang *et al.*, 2017; Tian and Meng, 2018). However, most of them only focus on the risk-taking incentives of stock options and their impact on risk-related decisions of innovation such as investment decisions (Guay, 1999; Coles, 2006; Ye *et al.*, 2015).

In contrast, research about the internal triggering mechanism of stock options on innovations remains limited. The only study of Chang *et al.* (2015) argues that the risk-taking incentives of stock options can motivate non-executive employees to take some risks in the innovation process. However, whether such an underlying mechanism could also be used to explain the incentive effect of stock options on innovation output in China? The recent research studies of Wang *et al.* (2017) and Tian and Meng (2018) both shed light on the subject area, but neither of them dipped into it to find out the actual internal driving mechanisms of stock options on firms' innovation behaviours. In addition, existing discussions of innovation-oriented elements design are mainly focussed on the incentive period or performance assessment criteria (Lerner and Wulf, 2007; Baranchuk *et al.*, 2014; Liu and Wang, 2018). However, it remains unclear whether the design of different elements such as the non-executive granting proportion, the granting range, the exercise proportion and the price-to-strike ratio, could also impact innovation outputs. Moreover, given the unique stock options schemes implemented amongst Chinese listed firms, whether such design of the exercise proportion, the exercise price and performance assessment criteria could provide more corporate innovation incentives? None of the existing research answers these questions thoroughly. More importantly, how can the design elements of a stock options contract affect its risk-taking incentives? These are some of the questions this research aims to address. It is expected to provide valuable theoretical references for the future design of stock options schemes amongst all listed firms in China.

This paper intends to examine how the internal triggering mechanism of stock options and its elements design may stimulate firms' innovation outputs. We start by talking about the innovative output-driving effect of stock options and the internal driving mechanism. Then based on the driving mechanisms identified, further discussion on contract elements design would be presented. Both propensity score matching (PSM) and the difference-in-difference model are applied on a sample comprising all listed companies who implement stock options to testify whether firms implementing stock options could deliver a significantly higher innovation output. Based on the conclusion, the internal driving mechanism of stock options in relation to innovation output is analysed in two dimensions, the performance-based incentives and the risk-taking incentives. In the end, focussing on six key contract elements, this paper further discusses the optimisation of elements design to enhance the risk-taking incentives of stock options on corporate innovation.

This paper makes four key contributions. Firstly, it enriches the studies on the subject area and confirms that stock options could indeed stimulate corporate innovation outputs. Secondly, this paper summarises the key differences identified and investigates how such differences in elements design may affect the stimulating effect of stock options on firms' innovation outputs. Meanwhile, this study further examines the impact of six key contract elements of stock options on firms' innovation performance. It has, hence, shed light on the more effective design of options contracts in the future. Last but not least, this research is also of significant practical contributions. It is found that setting a strict performance assessment criterion and high price-to-strike ratio may weaken the risk-taking incentives of stock options, and hence reducing its innovation incentivising impact. Such a result is closely related to the performance assessment criteria and the prohibition of repricing policies implemented by the Chinese Government. To maximise the positive impact of stock options on firms' innovation outputs, more flexibility and independence should be allowed to the listed firms in designing their stock options schemes.

2. Theoretical basis and research hypothesis

2.1 Stock options and enterprises innovation output

Based on the innovation theory, this paper argues that the implementation of stock options exerts a positive impact on corporate innovation. Innovation is often characterised by high risk due to significant uncertainties involved (Holmstro, 1989). It has been confirmed over time that a greater convexity of stock options facilitates increased risk-taking behaviour such as research and development (R&D) investment, thus leading to a higher level of innovation outputs (Guay, 1999; Coles, 2006; Chang *et al.*, 2015; Baranchuk *et al.*, 2014; Smith and Stulz, 1985). As a result, it is argued by Manso (2011) that long-term compensation incentives should be provided to stimulate innovation. A similar conclusion is also reached by Lerner and Wulf (2007) that the relationship between short-term incentives and innovation is insignificant. The long-term nature of stock options facilitates the incentive object to pursue high performance over the longer term. Rewarding incentive objects for long-term innovation is effective in increasing innovation outputs. In essence, innovation is human capital intensive and requires adequate human talent investments (Holmstro, 1989). According to the *Measures for the Administration*, the incentive object needs to remain in their job throughout the exercise period to be eligible to exercise their options. This requirement makes the equity incentives an effective mechanism for staff retention (Core and Guay, 2001). Oyer and Schaefer (2005) believe that stock options can attract and retain employees who are optimistic about the prospects of the company. These employees are more likely to create value for the company. That explains why many high-tech companies adopted the scheme to attract and retain top talents in their innovation team (Murphy, 2003). Finally, innovation involves well-developed knowledge-sharing processes and relies on high levels of collaboration. According to Team Motivation Theory, the explicit incentive mechanism of evaluating team performance against performance assessment criteria set in the stock options helps a team reach optimal efficiency (Che and Yoo, 2001).

In China, stock options have broader coverage. In recent years, there is also a tendency to focus more on key employees, especially those in technology-focussed roles (Xiao *et al.*, 2016). The wide range of incentive objects and the diversification of functions facilitate knowledge sharing amongst team members. Based on the above analysis, this paper proposes the first hypothesis:

H1. The implementation of stock options will improve the innovation output of a firm.

2.2 The mechanism of stock options driven innovation output

2.2.1 The mechanism of performance-based incentives. Hirshleifer and Suh (1992) point out that the distribution of project returns is uncertain and can be influenced by the effort and execution of agents. Jensen and Meckling (1976) illustrate that the principal may tie up the personal wealth of agents with the performance or the stock price of firms. In this paper, we refer to this incentive mechanism as the Performance-based incentives and measure its strength in terms of the sensitivity of the value of stock options to the stock price (Delta). For every 1% change in stock price, Delta measures the corresponding changes in the value of the stock options (Core and Guay, 2002). Based on the above analysis, this paper proposes the *H2a*:

H2a. Based on the performance-based incentives, the implementation of stock options should increase the innovation output of the firm.

2.2.2 The mechanism of risk-taking. As the personal wealth of incentive targets are less diversified than that of the shareholders, they tend to act more conservatively (Amihud and Lev, 1981). However, as innovative activities are associated with a high level of risk and it is, therefore, expected that incentive targets are incentivised to take more risks (Manso, 2011). Hirshleifer and Thakor (1992) also point out that to maintain their personal reputation, agents are more likely to choose some low-risk projects, and hence impair the innovation capacity of firms. Cabrales *et al.* (2008) claim that the risk-taking capacity of key innovators may contribute significantly to a firms' breakthrough innovation outputs. Therefore, this has called for a more suitable design of the incentive schemes, which can trigger more risk-taking behaviours. The convex nature of stock options makes it an appropriate choice as a higher stock price volatility may lead to increased personal wealth (Smith and Stulz, 1985).

Due to the asymmetry between the risk and reward of stock options, the return of the incentive target goes up along with an increased stock price when the innovation is successful. Even if the share price drops during the innovation process, the incentive targets can choose not to exercise their rights to avoid suffering a financial loss. Empirical studies have also found that firms that grant stock options typically deal with higher unsystematic risk and more innovative inputs (Coles, 2006; Low, 2009). Existing research has also found that stock options can increase the innovation output of firms by incentivising employees to take more risks during the innovation process (Chang *et al.*, 2015). This paper refers to this incentive mechanism as the risk-taking incentives and measures its strength in terms of the sensitivity of stock option values to stock price volatility (Vega). Vega is calculated as the change in the value of shares to a factor of 1% change in stock price volatility (Core and Guay, 2002). Based on the above analysis, this paper proposes the *H2b*:

H2b. Based on the risk-taking incentives, the implementation of stock options will increase the innovation output of the firm.

2.3 Elements design of stock options that drive enterprise innovation output

Previous studies have found that the elements designed may affect the risk-taking incentives of stock options (Bettis *et al.*, 2018; Core and Guay, 2002). Therefore, considering relevant regulations within the *Measures for the Administration*, this paper further investigates how the different combinations of elements may affect the risk-taking incentives of stock options.

2.3.1 Non-executive granting proportion. Technological advancements and innovation outputs of enterprises are often borne from initiatives led by non-executives (Chang *et al.*, 2015). Existing studies indicate that although non-executives have the willingness and ability to reduce corporate risk, they tend to be risk-averse, hence weakening the innovation capacity of firms (Bova *et al.*, 2015). Granting stock options to non-executives may address this issue effectively as it links the personal wealth of employees with corporate risk and incentivises them to take risks proactively (Chang *et al.*, 2015). The larger the proportion of non-executive grants in the stock option incentive plan, the stronger the correlation between the personal wealth of non-executives and the risk taken by firms. This, in turn, contributes to a higher level of innovation output of firms.

2.3.2 Granting range. Innovation is an intellectually intensive activity that requires teamwork amongst intellective employees (Holmstro, 1989). Studies have shown that broad-based stock options are useful for enhancing collaboration amongst employees, improving firm performance and innovation output (Hochberg and Lindsey, 2010; Fang *et al.*, 2015). However, some studies also argue that stock options have no significant effects on performance (Frye, 2004). The innovation incentive effect of stock options is more obvious in companies with a smaller number of employees (Chang *et al.*, 2015). This condition shows that there is also a "free-riding" problem associated with innovation activities. Therefore, when the stock option granting coverage is large, employees who hold a free-riding attitude within the innovation process can enjoy the benefits created by the others. This would then affect the sentiment of other team members and consequently reduce the innovation outputs of the firm and weaken the incentive effect through risk-taking.

2.3.3 Incentive period. The long-term nature and uncertainty of innovation require long-term compensation incentives. Many empirical studies have shown that long-term remuneration schemes tend to be more effective in stimulating firm innovations (Lerner and Wulf, 2007; Holthausen *et al.*, 1995). Some studies confirm that a relatively longer option incentive period may lead to increased innovation outputs as employees are given more time to try (Wang *et al.*, 2017; Chang *et al.*, 2015). This has made them more likely to benefit from successful innovations.

2.3.4 Exercise proportion. Due to the high-risk and long-term characteristics of innovation, early failure should be tolerated and long-term success should be rewarded when setting benchmarks for innovation motivation. Azoulay *et al.* (2011) point out that academic institutions that tolerate short-term failure and reward long-term success see greater innovation levels. Ederer and Manso (2013) also find that "exploratory" pay, which tolerates short-term failure and rewards for long-term success, may lead to more innovative behaviours in experimental objects. The incremental exercise proportion is an element design that can achieve the same purpose. It allows for a larger gain from the innovation success at the later stage. Meanwhile, the high correlation between risk and return encourages employees to take risks and improve innovation output.

2.3.5 Price-to-strike ratio. The price-to-strike ratio is measured as the ratio of the market price of the option to the strike price. It represents the profit margin of the incentive target. When the market price increases or the exercise price decreases, the price-to-strike ratio of stock options would increase, and hence leading to a higher personal gain of the incentive target.

Core and Guay (2002) find that the price-to-strike ratio of stock option and risk-taking incentives exhibit the inverted U shape. The risk-taking incentives will be maximised when the ratio of the market price to the strike price is set at 0.6. However, when the price-to-strike ratio increase continuously, the risk-taking incentives of stock options decrease accordingly. Thus, a high price-to-strike ratio of stock options will weaken the sensitivity between option value and risk-taking and also, the innovation outputs of firms.

2.3.6 Performance assessment criteria. Innovation requires an environment that tolerates failure. Acharya *et al.* (2013) find that well-designed labour laws can promote innovation progress. Azoulay *et al.* (2011) suggest that a research environment that tolerates failure allows researchers to be more innovative. In the study related to stock options, Bettis *et al.* (2018) find that performance assessment criteria may weaken the risk-taking incentives of stock options. Liu and Wang (2018) also find that strict performance assessment criteria may not contribute positively to firms' innovation outputs. This is because one of the criteria for the incentive target to exercise its options is to meet those prespecified performance assessment criteria. As a result, when the performance assessment criteria are tight, the option holders would have a higher possibility of unable to exercise the options granted. Under these conditions, the correlation between risk and reward will be weakened and the motivation provided for employees to engage in risky innovation activities would also become limited.

Based on the above analysis, this paper proposes the following hypothesis:

H3a. The larger the proportion of non-executive grants, the greater the risk-taking incentives of stock options on the innovation output of firms.

H3b. The larger the granting range, the smaller the risk-taking incentives of stock options on the innovation output of firms.

H3c. The longer the incentive period, the greater the risk-taking incentives of stock options on the innovation output of firms.

H3d. If the exercise proportion increases incrementally, the risk-taking incentives of stock options will have a greater impact on the innovation output of firms.

H3e. The risk-taking incentives of stock options on the innovation output of firms are smaller when the options are granted at a higher price-to-strike ratio.

H3f. The stricter the performance assessment criteria, the smaller the risk-taking incentives of stock options on the innovation output of firms.

3. Research design

3.1 Sample and data

3.1.1 Observed sample. This paper focusses on the stock option schemes implemented by the Chinese listed companies over the period of 2006 to 2016. During the sample period, listed companies announced 567 equity incentive plans with stock options. To reflect the actual impact of the implementation of stock options on innovation, we reduced our sample by excluding 177 plans that are terminated, 75 plans that use a combination of stock options and restricted stocks or stock appreciation rights, 8 plans for ST companies and 5 plans with missing data. The final sample includes 302 stock options only schemes announced and implemented by the non-ST listed firms in China from 2006 to 2016.

3.1.2 Matching samples and matching process. This paper adopts PSM to solve the sample self-selection problem. In the PSM process, this paper selects 20,149 firm-year observations with non-financial, non-ST companies and no missing data from 1st January 2005 to 31st December 2015. We use whether stock options are exercised as the dependent variable and regress on the independent variables which affect stock option implementation in the previous period. The probit model is as follows.

$$
\begin{aligned}
SO_{i,t} = {} & \theta_0 + \theta_1 Grow_{i,t-1} + \theta_2 Roe_{i,t-1} + \theta_3 Exe\_own_{i,t-1} + \theta_4 Tech_{i,t-1} + \theta_5 Dual_{i,t-1} \\
& + \theta_6 State_{i,t-1} + \theta_7 Leverage_{i,t-1} + \theta_8 Size_{i,t-1} + \theta_9 Hhl5_{i,t-1} \\
& + \theta_{10} Patent\_growth_{i,t-1} + Industry + Year + \varepsilon_{i,t}
\end{aligned}
$$

Amongst them, the dependent variable SO is a dummy variable that takes 1 when the company implements stock options and 0 otherwise. Considering that the implementation of equity incentives is mainly influenced by institutional background, corporate governance and firm characteristics (Lv *et al.*, 2011), this research chooses the following independent variables, firm growth (Lv *et al.*, 2011; Chourou *et al.*, 2008), return on equity (Roe) (Kroumova and Sesil, 2006), executive shareholding (Exe_own) (Lv *et al.*, 2011; Wei, 2000), high-tech industry (Tech) (Lv *et al.*, 2011; Kroumova and Sesil, 2006), duality (Dual) (Lv *et al.*, 2009), nature of control (State), debt ratio (Leverage) (Lu *et al.*, 2015), firm size (Size) (Lu *et al.*, 2015), equity concentration (Hhl5) (Xiao and Yu, 2012) and patent growth (Patent_growth) (Tian and Meng, 2018). In this paper, the high-tech industry is identified according to the 2012 industry classification criteria issued by the Securities Regulatory Commission and the "Key High-tech Fields Supported by the State".

The detailed definitions of all variables used in the probit model are shown in Table 3. The probit regression is used to calculate the probability of whether a firm would implement stock options each year. The nearest neighbour matching method and the 1:1 matching ratio are used to match the observation sample to the firm with the closest probability value in the same year. Due to word limitation, specific regression results can be provided upon request. This paper ultimately identifies a paired sample of 302 observations for which stock options are implemented. To test the validity of matching, this paper compares the group differences between the observed and matched samples before and after matching. The results are shown in Table 2.

It can be seen from Table 2 that there are significant differences between the observation and matched samples before matching. However, the *t*-tests between groups after matching are not significant, indicating that there is no significant difference between the observed and the matched sample after matching. The patent growth rate of the observed sample and the matched sample are also consistent, satisfying the assumption of a parallel trend.

All financial and patent data are extracted from Wind and CSMAR. Some of the data related to the stock options schemes are obtained by manually compiling draft announcements disclosed by the CNINF.

3.2 Model and variable

3.2.1 Difference-in-difference model. The innovation incentive effect of stock options can be verified by comparing the change in innovation output of the observation sample with that of the matched sample before and after the implementation of stock options. Therefore, in this paper, a difference-in-difference model is constructed to test *H1*, as shown in model (1):

		Mean		*t*-test	
Variables	Sample	Observed sample	Matched sample	*t*	$p > t$
Grow	Before matching	0.784	0.982	−9.33	0.000
	After matching	0.784	0.776	0.31	0.760
Roe	Before matching	0.098	0.055	12.96	0.000
	After matching	0.098	0.094	1.27	0.206
Exe_own	Before matching	0.148	0.075	17.72	0.000
	After matching	0.148	0.153	−0.75	0.454
Tech	Before matching	0.513	0.358	13.53	0.000
	After matching	0.513	0.525	−0.75	0.450
Dual	Before matching	0.335	0.207	13.18	0.000
	After matching	0.335	0.339	−0.26	0.797
State	Before matching	0.205	0.531	−28.20	0.000
	After matching	0.205	0.199	0.49	0.627
Leverage	Before matching	0.410	0.458	−9.74	0.000
	After matching	0.410	0.406	0.50	0.617
Size	Before matching	21.867	21.777	2.68	0.007
	After matching	21.867	21.841	0.34	0.734
Hhl5	Before matching	0.166	0.177	−4.04	0.000
	After matching	0.166	0.165	0.25	0.826
Patent_growth	Before matching	0.513	0.359	13.53	0.000
	After matching	0.513	0.525	−0.75	0.453

Notes: "Before matching" refers to the sample before the propensity score matching is used and "after matching" refers to the sample after the nearest neighbour matching is used. "Observed sample" and "matched sample" refer to companies that have implemented and have not implemented stock options, respectively

Table 2.
Matched sample results test

$$Patents_{i,t+1} = \alpha_0 + \alpha_1 SO_{i,t} + \alpha_2 Post_{i,t} + \alpha_3 SO_{i,t} * Post_{i,t} + \alpha_4 R\&D_{i,t} + \alpha_5 Dual_{i,t} + \alpha_6 Cash_{i,t} + \alpha_7 Roe_{i,t} + \alpha_8 Grow_{i,t} + \alpha_9 Size_{i,t} + \alpha_{10} Tech_{i,t} + Industry + Year + \varepsilon_{i,t} \quad (1)$$

The selection of variables in Model (1) is as follows. The dependent variable of the model is innovation output. Many studies use the number of patent applications, the number of patents granted and the number of patent citations as proxies for innovation output. Griliches (1990) argues that the patent granting process is uncertain and susceptible to the influence of other human factors. Hence, the number of patent applications is a better reflection of the real level of innovation of a firm than the number of patents granted. Besides, China lacks access to patent citation data. Therefore, this paper uses the number of patent applications (Patents) to measure the innovation output of a firm. Patents can be classified into three categories, the patent for invention, the patent for utility model and the patent for industrial design. Zhang and Feng (2007) argue that these three types of patents reflect different degrees of innovation. To reflect a firm's innovation level comprehensively, this paper chooses the sum of the three types of patent applications as a proxy for innovation output.

The independent variables of the model include whether stock options (SO) are implemented, before and after the year of implementation (Post) and the interaction term of the two (SO*Post). SO takes the value of 1 when the firm implements stock options and 0 otherwise. Post takes the value of 1 when the year is after the implementation of stock options and 0 otherwise. Based on *H1*, this paper expects the coefficient of SO*Post to be significantly positive.

The control variables include R&D investment (R&D), duality (Dual) (Zhao and Wen, 2011), cash asset ratio (Cash) (Murphy, 2003), return on equity (Roe) (Ye *et al.*, 2015), firm growth (Grow) (Murphy, 2003), firm size (Size) (Shu *et al.*, 2007) and high-tech industry (Tech).

3.2.2 Multiple regression model. In this paper, we use the multiple linear regression model to investigate the driving mechanism of stock options on innovation output of firms, that is, to validate *H2a* and *H2b*, as shown in model (2). Amongst these, Delta denotes the stock price sensitivity of the stock options. *H2a* is verified when Delta is significantly positive. Vega denotes the stock price volatility sensitivity of stock options. *H2* b is verified when Vega is significantly positive. Delta and Vega are calculated with reference to Core and Guay (2002):

$$Patents_{i,t+1} = \gamma_0 + \gamma_1 Delta_{i,t} + \gamma_2 Vega_{i,t} + \gamma_3 Elements_{i,t} + \gamma_4 Vega_{i,t} * Elements_{i,t} + \gamma_5 R\&D_{i,t} + \gamma_6 Dual_{i,t} + \gamma_7 Cash_{i,t} + \gamma_8 Roe_{i,t} + \gamma_9 Grow_{i,t} + \gamma_{10} Size_{i,t} + \gamma_{11} Tech_{i,t} + Industry + Year + \varepsilon_{i,t} \quad (2)$$

To verify *H3a-H3f*, this paper multiplies the six option elements with the risk-taking incentives (Vega) based on model (2) and establishes a multiple linear regression model (3). This paper expects to investigate the impact of the risk-taking incentives on the innovation output of firms when the stock option elements satisfy the hypothesis conditions.

$$Patents_{i,t+1} = \gamma_0 + \gamma_1 Delta_{i,t} + \gamma_2 Vega_{i,t} + \gamma_3 Elements_{i,t} + \gamma_4 Vega_{i,t} * Elements_{i,t} + \gamma_5 R\&D_{i,t} + \gamma_6 Dual_{i,t} + \gamma_7 Cash_{i,t} + \gamma_8 Roe_{i,t} + \gamma_9 Grow_{i,t} + \gamma_{10} Size_{i,t} + \gamma_{11} Tech_{i,t} + Industry + Year + \varepsilon_{i,t} \quad (3)$$

Contract elements of the model (3) are defined as follows. The non-executive granting proportion (Non) is equal to the number of stock options granted to non-executive divided by the total number of stock options granted. Granting range (Range) is equal to the total number of shares granted divided by the total number of shares issued by the company (Hochberg and Lindsey, 2010). Incentive period (T), with reference to the classification criterion of Lv *et al.* (2009) for the incentive period, T takes the value of 1 when the incentive period is greater than or equal to 5 years and 0 otherwise. Exercise proportion (Exep), in this paper, the distribution of the exercise proportion is divided into three categories, increasing year by year, average distribution or decreasing year by year. Exep takes the value 1 when the exercise proportion increases year by year, otherwise, it is 0. The price-to-strike ratio (Premium) is measured by the opening price of the stock in the year of granting divided by the exercise price. Performance assessment criteria (Perf), this paper compares each performance assessment criteria to the previous three years of the company to identify whether it is greater than the value of any of the previous three years or greater than the mean of the previous three years (considering outliers of standard deviation) (Lv *et al.*, 2009). If any performance assessment criteria satisfy the above conditions, this paper classifies them as "strict" and assigns the value 1 to the variable Perf, otherwise, it equals 0. The indicators of performance assessment are mostly growth rates or yield indicators. When the standard deviation of the current three-year performance indicators is greater than 50%, this paper considers that there is an abnormal value of the standard deviation. Therefore, this paper uses only the average of the previous three years as a criterion to determine whether the performance assessment criteria are strict or not to smooth out the outliers in any given year. The control variables used for model (2) and model (3) are identical to the ones included in the model (1). Variables are defined in Table 3 (We only present variables, which are not mentioned previously).

4. Empirical results and analysis

To test the hypotheses proposed above, this paper applies the difference-in-difference method on the observed sample (1,825 observations) and the paired sample (1,742 observations) before and after implementing the stock options. Meanwhile, for the observation sample (933 observations), the multiple linear regression model is applied.

4.1 Descriptive statistical results

The descriptive statistics of the main variables in the difference-in-difference model and the multiple linear regression model constructed in this paper are shown in Table 4. The descriptive statistics of the elements design are shown in Table 1.

From the above table, it can be seen that the means and medians of the variables in the two models are relatively close to each other, indicating that the distribution of each variable is close to a symmetrical distribution. The mean values of the independent variables "implementation of stock options (SO) or not" and "implementation year before and after (Post)" are close to 0.5, indicating that the observed and paired samples are evenly distributed. The 1% change in the stock price leads to the average change in stock option

Variables	Definitions	Calculation methods
Patents	Number of patent applications	The sum of invention, utility model and industrial design patent applications plus 1 and take the natural logarithm
SO	Whether to implement stock options	The value is 1 when the company implements stock options, otherwise, it is 0
Post	Before and after the year of implementation	The value is 1 when the year is after implementation, otherwise, it is 0
Delta	Option stock price sensitivity	The first derivative of the option value to stock price
Vega	Option stock price volatility sensitivity	The first derivative of the option value to stock price volatility
R&D	R&D investment	R&D investment/operating income
Grow	Growth of the company	Total assets/market value
Roe	Return on equity	Net profit/owner's equity
Exe_own	Executive shareholding	The ratio of shares held by senior management to the total share capital
State	Nature of control	The value is 1 when the final controller is state-owned, otherwise, it is 0
Dual	Duality	The value is 1 when the chairman is also the manager, otherwise, it is 0
Cash	Cash assets ratio	Cash and cash equivalents at the end of the period/total assets
Size	Firm size	The natural logarithm of the company's total assets
Hhl5	Equity concentration	The sum of the squares of the company's top 5 shareholders
Tech	High-tech industry	According to the 2012 industry classification standards of the China Securities Regulatory Commission and the "key high-tech fields supported by the state", it is 1 if it is a high-tech industry, otherwise, it is 0
Patent_growth	Patent growth rate	The growth rate of patent applications in the past three years
Non	Non-executive granting proportion	Number of stock options granted to non-executives/total number of stock options
Range	Granting range	Total number of shares granted/total number of company shares
T	Incentive period	The value is 1 if the incentive period is greater than or equal to five years, otherwise, it is 0
Exep	Exercise proportion	The value is 1 when the exercise proportion increases year by year, otherwise, it is 0
Premium	Price-to-strike ratio	The opening price of the stock in the year of granting/exercise price
Perf	Performance assessment criteria	The value is 1 when any performance assessment criteria are greater than the value of any of the previous three years or greater than the mean of the previous three years, otherwise, it is 0

Table 3.
Variable definitions

value (Delta) by 560,000. Then, a 1% chance of the stock volatility leads to an average change of the stock option value (Vega) by 263,000.

4.2 Correlation analysis

To investigate the correlation between the dependent and the independent variables and to test whether there is a multicollinearity problem between main variables, this paper calculates the Pearson correlation coefficient of the main variables in the model and reports the results in Tables 5 and 6.

The absolute values of the correlation coefficients between the variables in both tables are less than 0.75 and the VIF of each variable is less than 5 after the VIF test, indicating that there is no multicollinearity between the main variables.

Table 4. Descriptive statistical result

Difference-in-difference model							Multiple linear regression model						
Variables	Mean	SD	p25	p50	p75	*n*	Variables	Mean	SD	p25	p50	p75	*n*
Patents	2.524	1.803	1.098	2.708	3.806	3,567	Patents	3.227	1.809	1.946	3.401	4.344	933
SO	0.512	0.500	0	1	1	3,567	Delta(10^6)	0.560	0.689	0.144	0.330	0.712	933
Post	0.492	0.500	0	0	1	3,567	Vega(10^6)	0.263	0.345	0.075	0.163	0.309	933
R&D	0.047	0.070	0	0.031	0.057	3,567	R&D	0.067	0.095	0.011	0.041	0.079	933
Dual	0.331	0.471	0	0	1	3,567	Dual	0.375	0.484	0	0	1	933
Cash	0.210	0.168	0.090	0.158	0.230	3,567	Cash	0.194	0.143	0.091	0.152	0.252	933
Roe	0.093	0.095	0.050	0.089	0.137	3,567	Roe	0.104	0.087	0.061	0.102	0.147	933
Grow	0.736	0.677	0.313	0.512	0.890	3,567	Grow	0.749	0.811	0.300	0.492	0.807	933
Size	21.768	1.200	20.921	21.624	22.471	3,567	Size	22.171	1.241	21.300	21.953	22.841	933
Tech	0.539	0.499	0	1	1	3,567	Tech	0.517	0.500	0	1	1	933

Table 5. Pearson correlation coefficient of the differences-in-differences model

	Patents	SO	Post	R&D	Dual	Cash	Roe	Grow	Size	Tech
Patents	1									
SO	0.190***	1								
Post	0.168***	0.057***	1							
R&D	0.100***	0.136***	0.0643***	1						
Dual	0.098***	0.077***	0.0176	0.147***	1					
Cash	−0.051***	0.121***	−0.1418***	0.306***	0.135***	1				
Roe	0.022	0.042**	−0.0298*	−0.015	−0.009	0.032*	1			
Grow	−0.015	−0.008	−0.014	−0.211***	−0.161***	−0.286***	−0.017	1		
Size	0.305***	0.103***	0.221***	−0.167***	−0.185***	−0.279***	0.042**	0.515***	1	
Tech	0.205***	−0.047***	0.015	0.300***	0.069***	0.187***	0.009	−0.222***	−0.21***	1

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 6. Pearson correlation coefficient of multiple linear regression model

	Patents	Delta	Vega	R&D	Dual	Cash	Roe	Grow	Size	Tech
Patents	1									
Delta	0.141***	1								
Vega	0.177***	0.622***	1							
R&D	0.020	−0.002	−0.073**	1						
Dual	0.098***	−0.013	−0.017	0.153***	1					
Cash	−0.115***	−0.082**	−0.121***	0.279***	0.061*	1				
Roe	0.034	0.223***	0.095***	−0.041	−0.087***	0.109***	1			
Grow	0.031	0.061*	0.307***	−0.272***	−0.149***	−0.278***	−0.007	1		
Size	0.213***	0.441***	0.568***	−0.276***	−0.185***	−0.311***	0.172***	0.668***	1	
Tech	0.155***	−0.048	−0.093***	0.382***	0.072	0.187***	−0.083**	−0.261***	−0.262***	1

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

4.3 Empirical results and analysis

4.3.1 Regression results for stock options implementation and innovation output. To test the hypothesis of whether the implementation of stock options can promote innovation output, this paper constructs a difference-in-difference model, as shown by the model (1). Both the industry and year dummy variables are controlled and the regression results are summarised in Table 7.

Patents	Coefficient	SD	*t*-value	*p*-value
SO	0.434***	0.064	6.82	0.000
Post	−0.061	0.068	−0.90	0.366
SO*post	0.262***	0.089	2.94	0.003
R&D	1.229***	0.291	4.23	0.000
Dual	0.316***	0.049	6.52	0.000
Cash	−0.276*	0.153	−1.80	0.072
Roe	0.041	0.059	0.70	0.483
Grow	−0.274***	0.041	−6.65	0.000
Size	0.737***	0.025	29.35	0.000
Tech	0.355***	0.055	6.49	0.000
_Cons	−15.111***	0.652	−23.18	0.000
n = 3,567		Adj-R^2 = 48.06%		

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 7. Regression results of stock options implementation and innovation output

It can be found that the coefficient of the interaction term, SO*Post is 0.262 and is significant at a 1% level. It, therefore, suggests that after the implementation of the stock options, the innovation outputs of firms also increased. This is consistent with the proposition of *H1*.

4.3.2 Regression results of stock options on the innovation output driving mechanism. In this paper, the Multiple Linear Regression model, i.e. model (2), is used to investigate the driving mechanism of stock options on innovation output from two dimensions, the risk-taking incentives and the performance-based incentives. Both the industry and year dummy variables have been controlled and the regression results are summarised in Table 8.

As shown in Table 8, the coefficient of Delta is insignificant, indicating that the performance-based incentives do not contribute to the innovation output of firms. Therefore, *H2a* is not verified. The coefficient of Vega is significantly positive ($p < 0.05$), indicating that the risk-taking incentives of stock options can promote firms' innovation by increasing the incentive target's risk-taking ability, hence verifying *H2* b. Although Delta motivates the incentive targets to work harder, a higher Delta also exposes the option holders to a higher risk level. As a larger Delta means that the incentive target will face a greater loss when the share price drops by 1%, the option holders may refuse to bear any additional risks to avoid losses (Carpenter, 2000). It is obvious that compared with working hard, the risk-taking

Patents	Coefficient	SD	*t*-value	*p*-value
Delta	0.063	0.090	0.71	0.481
Vega	0.381**	0.176	2.16	0.031
R&D	1.781***	0.545	3.27	0.001
Dual	0.196**	0.090	2.18	0.029
Cash	−0.779**	0.331	−2.36	0.019
Roe	0.556	0.535	1.04	0.298
Grow	−0.225***	0.085	−2.65	0.008
Size	0.769***	0.064	12.09	0.000
Tech	0.184*	0.108	1.71	0.088
Cons	−14.881***	1.411	−10.55	0.000
n = 933		Adj-R^2 = 52.22%		

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 8. Multiple linear regression results of stock options on the innovation output driving mechanism

ability of incentive targets is more important for the innovation outputs of enterprises. Taking the positive impact of stock options on firms' innovation into consideration, this paper argues that although an increase in Delta may increase the risk exposure of option holders, an increase in Vega may offset Delta's risk-averse effect to some extent (Low, 2009). Therefore, in general, the implementation of stock options can increase the risk-taking ability of the incentive targets, and thus promote innovation.

4.3.3 The regression results of stock option elements design and innovation output. From the above analysis, we may conclude that the driving mechanism of stock options on innovation is through risk-taking incentives. This paper uses model (3) to further discuss the impact of risk-taking incentives on innovation output under different elements design. The results are shown in Table 9.

It can be seen from Table 9 that the coefficient of Vega*Non is significant at 1% level, indicating that the risk-taking ability of non-executives plays an essential role in firms' innovation outputs. *H3a* is, hence, proved. The coefficient of Vega*Range is negative and is significant at 1% level, suggesting that the risks and rewards of innovative activities are spread out when the granting range is wide. This can be explained as the aforementioned "free-riding" problem. Thus, the *H3* b is also verified.

The coefficient of Vega*T is positive and significant at a 5% level, consistent with *H3c* that a longer incentive period can lead to higher innovation activities of the firm. The coefficient of Vega*Exep is positive and significant at a 1% level, confirming that an increase in the exercise portion can effectively reward forward innovation success and contribute to the risk-taking incentives of stock options. *H3d* is, therefore, verified. The coefficient for Vega*Premium is insignificant, so it seems that whether the stock options are in-the-money or not would affect the risk-taking incentives of stock options, and hence the innovation output of firms. Finally, the coefficient of Vega*Perf is negative and significant at 1%, suggesting that a stricter performance assessment may weaken the risk-taking incentives of stock options. This is in line with the conclusion reached by Manso (2011) that innovation requires tolerance of failure.

4.4 Robustness test

4.4.1 Using instrumental variables to address the endogenous problem. Although the use of PSM in this study could eliminate the problem of sample self-selection to some extent, there may still be other endogeneity issues such as reverse causality or omitted variables. Therefore, with reference to the study of Hochberg and Lindsey (2010) and Chang *et al.* (2015), this paper adopts the proportion of companies with zero patent but also implement stock options to total companies that implement stock options within the same industry and the same region (SO_I) as an instrumental variable for whether a company implements stock options (SO). In addition, referring to the study of Ye *et al.* (2015), this paper uses industry mean values (Delta_I and Vega_I) as instrumental variables for the performance-based incentives (Delta) and the risk-taking incentives (Vega). From Table 10, it can be seen that the Hausman test suggests that there is an endogeneity problem in the original regression results ($p < 0.01$), but the two-stage regression results are generally consistent with the previous findings.

In addition, this paper also compares the 177 plans that are announced but terminated. It is again confirmed that firms that implement the stock options plan generally have much-improved innovation outputs, consistent with *H1*.

4.4.2 Measuring innovation output using different indicators. The innovation output of enterprises can be measured in various ways such as the quantity, quality and efficiency of innovation outputs. In the above analysis, the quantity of innovation output is measured by

Table 9. Regression results of stock options element design and innovation output

	Non-executive granting proportion (1)	Granting range (2)	Incentive period (3)	Exercise proportion (4)	Price-to-strike ratio (5)	Performance assessment criteria (6)
Delta	0.088 (0.99)	0.057 (0.60)	0.063 (0.70)	0.020 (0.22)	0.061 (0.67)	0.069 (0.78)
Vega	−1.973** (−2.52)	1.167*** (4.13)	0.040 (0.16)	−0.237 (−1.08)	0.059 (0.11)	0.806*** (3.92)
Non	0.357 (1.29)					
Vega*non	2.534*** (3.00)					
Range		0.086*** (2.72)				
Vega* range		−0.250*** (−3.65)				
T			−0.155 (−1.40)			
Vega*T			0.521** (2.00)			
Exep				0.038 (0.35)		
Vega*exep				1.097*** (4.39)		
Premium					−0.009 (−0.05)	
Vega* premium					0.362 (0.68)	
Perf						−0.051 (−0.43)
Vega*perf						−1.225*** (−4.86)
R&D	1.697*** (3.14)	1.830*** (3.37)	1.702*** (3.12)	1.785*** (3.31)	1.797*** (3.29)	1.736*** (3.25)
Dual	0.154* (1.71)	0.180** (2.01)	0.187** (2.07)	0.151* (1.67)	0.192** (2.13)	0.200** (2.27)
Cash	−0.877*** (−2.67)	−0.790** (−2.38)	−0.769** (−2.32)	−0.680** (−2.07)	−0.774** (−2.33)	−0.699** (−2.16)
Roe	0.343 (0.65)	0.453 (0.85)	0.544 (1.02)	0.633 (1.13)	0.541 (1.01)	0.249 (0.47)
Grow	−0.196** (−2.33)	−0.270*** (−3.10)	−0.237*** (−2.79)	−0.231*** (−2.75)	−0.223*** (−2.62)	−0.268*** (−3.21)
Size	0.759*** (12.00)	0.794*** (11.26)	0.764*** (11.72)	0.779*** (12.16)	0.769*** (12.06)	0.785*** (12.59)
Tech	0.172 (1.60)	0.154 (1.43)	0.187* (1.73)	0.151 (1.40)	0.187* (1.73)	0.212** (2.00)
Cons	−14.531*** (−10.38)	−15.682*** (−9.78)	−14.653*** (−10.20)	−15.094*** (−10.56)	−14.845*** (−10.48)	−15.036*** (−9.85)
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R^2 (%)	53.16	52.82	52.33	53.68	52.14	54.23
n	933	933	933	925	933	933

Notes: $***p < 0.01$; $**p < 0.05$; $*p < 0.1$

Table 10. The 2SLS regression results using instrumental variables

	First stage	Second stage	First stage		Second stage
	SO	Patents	Delta	Vega	Patents
	(1)	(2)	(3)	(4)	(5)
SO		1.430*** (9.46)			
SO_I	0.977*** (23.77)				
Delta					−1.372** (−2.04)
Vega					5.552*** (3.70)
Delta_I			0.453*** (2.99)	−0.156** (−2.01)	
Vega_I			0.545 (1.38)	0.982*** (4.86)	
R&D	0.192** (2.28)	1.114*** (3.65)	0.393* (1.70)	0.225* (1.89)	1.274 (1.62)
Dual	0.043*** (3.04)	0.283*** (5.54)	0.082** (2.12)	0.042** (2.11)	0.056 (0.40)
Cash	−0.041 (−0.93)	−0.019 (−0.12)	−0.025 (−0.18)	0.077 (1.07)	−1.104** (−2.38)
Roe	0.038** (2.20)	0.026 (0.43)	0.703*** (3.10)	−0.120 (−1.03)	2.517** (2.53)
Grow	−0.038*** (−3.22)	−0.233*** (−5.38)	−0.252*** (−7.13)	−0.071*** (−3.90)	−0.247** (−1.37)
Size	0.069*** (9.57)	0.683*** (24.28)	0.347*** (14.75)	0.190*** (15.73)	0.299 (1.22)
Tech	−0.001 (−0.08)	0.368*** (6.43)	−0.006 (−0.13)	−0.002 (−0.07)	0.127 (0.85)
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
F-value	36.12***	78.56***	19.99***	17.88***	16.52***
Hausman test	44.65***	N/A	11.78***		N/A
Adj-R^2 (%)	27.23	43.61	40.21	37.41	6.35
n	3,567	3,567	933	933	933

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

the total number of patent applications. In the following part, the quality of innovation output will be measured by the number of invention patent applications and the efficiency of innovation output will be measured by the ratio of the total number of patent applications to total R&D investments. Due to the word limit, only the regression results of key variables are presented. The control variables, year and industry dummy variables have been controlled, as shown in Table 11.

4.4.3 Measuring of stock options elements design using different indicators. In this section, we further run the regression by making a few adjustments. We replace the non-executive granting proportion (Non) with the ratio of non-executive grants to the total number of people granted and replace the granting range (Range) with the number of people granted to the total number of employees of a company. We assign 1 if the incentive period (T) is greater than five years and 0 if it is shorter.

The exercise proportion (Exep) is defined as 1 when it increases, and 0 when it decreases. The price-to-strike ratio is replaced by the year-end share price of the year granted divided by the exercise price. Besides, this paper compares each performance assessment measurement to those of the past three years to identify whether it is greater than any of the value of the previous three years' (considering outliers of standard deviation) (Lv *et al.*, 2009). If over half of the measurements satisfy the above criteria, we would conclude that the performance assessment criteria (Perf) is considered strict and a value of 1 would then be assigned. Otherwise, the performance assessment criteria are considered to be loose and a value of 0 would be assigned.

From Table 12, it can be seen that the regression results are consistent with the original findings in general. However, the coefficient of the non-executive granting proportion turns insignificant. This can be explained as when compared with the percentage of non-executive grants to total grants, the percentage of stock options granted to non-executives to total options granted is a better indicator to measure the incentive intensity for non-executives.

Table 11. Robustness test results using different innovation output indicators

Innovation output quality	Model (1)	Model (2)	Model (3)					
			Non	Range	T	Exep	Premium	Perf
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SO	0.426*** (7.26)							
Post	−0.028 (−0.44)							
SO*post	0.226*** (2.76)							
Delta		0.047 (0.52)	0.068 (0.77)	0.017 (0.18)	0.045 (0.50)	0.007 (0.08)	0.046 (0.51)	0.038 (0.43)
Vega		0.680*** (3.87)	−1.292 (−1.65)	1.100*** (3.89)	0.459* (1.88)	0.080 (0.36)	0.245 (0.48)	1.174*** (5.68)
Elements			0.430 (1.55)	0.068** (2.16)	−0.111 (−1.00)	0.026 (0.24)	−0.062 (−0.36)	0.232 (1.95)
Vega*elements			2.110**	−0.143** (−2.09)	0.336 (1.29)	1.061*** (4.25)	0.477 (0.90)	−1.227*** (−4.84)
Innovation output efficiency	Model (1)	Model (2)	Model (3)					
			Non	Range	T	Exep	Premium	Perf
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SO	0.013*** (3.65)							
Post	−0.007* (−1.77)							
SO*post	0.016*** (3.12)							
Delta		−0.001 (−0.04)	0.001 (0.21)	−0.003 (−0.57)	−0.001 (−0.14)	−0.001 (−0.11)	−0.001 (−0.05)	0.001 (0.03)
Vega		0.045*** (4.41)	−0.108** (−2.37)	0.091*** (5.58)	0.019 (1.36)	0.007 (0.59)	0.022 (0.74)	0.070*** (5.90)
Elements			−0.013 (−0.81)	0.007*** (3.93)	−0.015** (−2.28)	−0.001 (−0.22)	−0.003 (−0.33)	−0.003 (−0.39)
Vega*elements			0.168*** (3.42)	−0.016*** (−3.93)	0.039*** (2.61)	0.065*** (4.50)	0.025 (0.82)	−0.072*** (−4.97)

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 12.
The results of the robustness test using different indicators to measure the elements of the stock option plan

	Non-executive granting proportion	Granting range	Incentive period	Exercise proportion	Price-to-strike ratio	Performance assessment criteria
Delta	0.064 (0.71)	0.032 (0.36)	0.033 (0.31)	−0.056 (−0.55)	−0.033 (−0.34)	0.092 (1.03)
Vega	0.899 (0.43)	0.689*** (3.33)	−0.096 (−0.36)	0.256 (0.84)	0.129 (0.39)	0.569*** (2.98)
Elements	−0.180 (−0.48)	−0.189 (−0.25)	−0.436*** (−2.63)	0.275* (1.91)	0.086 (1.15)	−0.116 (−1.07)
Vega*elements	−0.509 (−0.24)	−3.334** (−2.23)	0.855** (2.21)	0.595* (1.90)	0.444 (1.46)	−0.813*** (−3.01)
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R^2 (%)	52.15	52.65	52.28	57.90	52.56	54.09
n	933	933	545	635	933	933

Notes: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

This is also consistent with our hypothesis that when a large number of employees are granted stock options, the "free-riding" problem would become more serious, and hence weaken the innovation capacity of firms.

4.4.4 Using group regression to replace the interaction term. In examining the elements design of stock options and the innovation output of firms, some conclusions have been drawn based on the interaction terms of the contract elements and Vega. However, this approach fails to show the relationship between the risk-taking incentives and innovation output under different elements design. Therefore, in this section, the sample is re-grouped according to the high and low non-executive granting proportions (grouped by mean), large and small granting ranges (grouped by mean), long and short incentive periods, incremental and non-incremental exercise proportions, high and low price-to-strike ratio (grouped by mean) and strict and lose performance assessment criteria. The *H3a-H3f* are retested with the results summarised in Table 13 below. The Chow-test is also applied to investigate whether the difference in Vega coefficients between groups is significant.

From Table 13, it can be seen that the results of the group test are basically consistent with the previous findings. The risk-taking incentives in the group regression are significant ($p < 0.1$) when the price-to-strike ratio is low, indicating that the low price-to-strike ratio of stock options is conducive to the risk-taking incentives. Therefore, the *H3e* is initially verified, but the results failed the intergroup Chow test.

4.4.5 Further group test. As the non-executive granting proportion, the granting range and the price-to-strike ratio are continuous variables, there could be a non-linear relationship between these variables and the dependent variable. From Table 1, it can be seen that the granting range and the price-to-strike ratio of stock options in listed companies of China vary widely. To accurately capture the effect of elements design on risk-taking incentives and to overcome the issue of possible non-linear relationships, this paper further refines the group regressions on the three elements. With reference to Ouimet and Zarutskie (2014), in this paper, the sample is divided into four groups according to the value of each variable with equal spacing and the regression coefficients of group (4), group (5) and group (12) with the risk-taking incentives (Vega) of other groups are tested by Chow-test. The results are shown in Table 14.

From Table 14, it can be seen that the coefficient of the risk-taking incentives (Vega) in the group (4) is significantly positive ($p < 0.01$) and the inter-group Chow test of the group (4) with a group (1) is significant ($p < 0.05$), indicating that the risk-taking incentives are more significant when the proportion of non-executive grants is greater than 90%. The coefficient of risk-taking incentives (Vega) in the group (5) is positive ($p < 0.1$) and the inter-group Chow test of the group (4) with a group (8) is significant ($p < 0.01$), indicating that the risk-taking incentives are better when the percentage of shares granted is less than 2.5%. The Vega coefficient in the group (12) is significantly negative ($p < 0.05$) and the intergroup Chow test of the group (12) and the rest of the groups is significant, indicating that a premium above 30% when granting will weaken the incentive of the risk-taking incentives on innovation. Therefore, *H3e* is supported.

5. Conclusions and recommendations

This paper uses a sample of all stock option schemes implemented by the Chinese listed companies over the period of 2006 to 2016 and applies the PSM, the difference-in-difference model and the multiple linear regression models to examine the incentivising effect of stock options on innovation outputs, the internal driving mechanisms of stock options on innovations and the design of innovation-oriented stock options elements.

Table 13. Robustness test results of stock options elements design and innovation output using group regression

	Non-executive granting proportion		Granting range		Incentive period	
	High	Low	Large	Small	Large	Small
	(1)	(2)	(3)	(4)	(5)	(6)
Delta	−0.074 (−0.66)	0.190 (1.37)	0.060 (0.53)	0.125 (0.80)	0.121 (0.78)	−0.053 (−0.46)
Vega	0.682*** (3.36)	−0.160 (−0.44)	−0.480** (−2.00)	0.756*** (2.82)	0.625** (2.41)	−0.155 (−0.59)
Chow-test	4.61**		13.32***		4.04**	
n	469	464	364	569	539	394
	Exercise proportion		Price-to-strike ratio		Performance assessment criteria	
	Increasing	Non−increasing	High	Low	Strict	Loose
	(7)	(8)	(9)	(10)	(11)	(12)
Delta	−0.113 (−1.00)	0.218 (1.61)	0.069 (0.46)	0.012 (0.10)	0.032 (0.25)	0.086 (0.65)
Vega	0.555*** (2.59)	−0.350 (−1.28)	0.119 (0.33)	0.410* (1.85)	−0.573** (−2.56)	0.873*** (3.91)
Chow-test	8.65***		0.57		20.93***	
n	449	476	397	536	676	257

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Non-executive granting proportion	<70%	70%~80%	80%~90%	>90%
	(1)	(2)	(3)	(4)
Delta	0.202 (1.12)	0.771** (2.52)	−0.126 (−0.50)	−0.105 (−0.94)
Vega	−0.249 (−0.67)	−0.083 (−0.13)	0.388 (1.11)	0.785*** (4.06)
Chow-test	6.15**	1.79	0.99	–
n	299	131	257	246
Granting range	<2.5%	2.5%~5%	5%~7.5%	>7.5%
	(5)	(6)	(7)	(8)
Delta	0.278 (0.91)	0.002 (0.01)	0.092 (0.61)	0.194 (1.39)
Vega	0.674* (1.80)	−0.015 (−0.05)	−0.064 (−0.17)	−1.861*** (−2.88)
Chow-test	–	1.90	1.96	11.52***
n	404	360	98	71
Price-to-strike ratio	<0.7	0.7~1	1~1.3	>1.3
	(9)	(10)	(11)	(12)
Delta	−0.164 (−0.79)	0.427** (2.49)	0.159 (0.90)	−0.431*** (−4.63)
Vega	2.355*** (4.74)	−0.454 (−1.32)	0.543** (2.52)	−2.154** (−2.22)
Chow-test	17.33***	2.74*	7.39***	–
n	91	389	350	103

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 14. Further group regression of non-executive granting proportion, granting range and price-to-strike ratio

Several conclusions are reached. First of all, consistent with the earlier study of Lerner and Wulf (2007), companies, which implement stock options are found of having an increased innovation output when compared with enterprises that fail to implement stock options. Secondly, focussing on the driving mechanism of stock options, this study confirms that the options scheme could enhance the incentive targets' innovation capacity effectively as it may increase the risk-taking capacity of the individuals. Although the performance-based incentives of stock options can encourage employees to work harder, declining stock prices can generate a risk-averse effect on the incentive targets and make them unwilling to take risks. This would, in turn, reduce the innovation output of firms. Such a conclusion is consistent with the findings of Brockhaus (1980) that the innovation capacity and the risk-taking capacity are critical factors for innovation success. Thirdly, based on the analysis of the contract elements, it is found that a favourable internal environment can be established to promote innovation performance if the stock options are granted to a larger proportion of non-executives, only covering a limited number of employees, with an increased exercise proportion, covering a relatively longer incentive period, having a low price-to-strike ratio and are evaluated against relatively loose performance assessment criteria.

Based on the above findings, this paper proposes several recommendations. Firstly, as stock options is an effective compensation method to stimulate innovation, it should be adopted by firms that want to increase innovation outputs. Secondly, to maximise the desired effect of the stock options scheme, the contract elements should be carefully designed to cover more non-executives but only with a limited granting range, offer longer incentive periods, incremental exercise proportions and are assessed against less rigid performance assessment criteria. Thirdly, given the potential negative impact of excessive price-to-strike ratio on the risk-taking incentives of the options schemes, companies should reduce the timing behaviour when choosing announcement dates and avoid granting deep-in-the-money stock options. Moreover, when firms' designing the performance assessment criteria related to the stock options, not only those conventional accounting indications but all other measurements which may capture the innovation activities such as R&D

investment index and sales revenue generated from new products, should also be considered. This may better incentivise employees to get engaged in innovation activities. Finally, it seems that the current tight government regulations on the performance assessment criteria and controls over repricing are unable to provide appropriate incentives to firms' innovations. Over the longer term, more flexibilities should be given to all listed firms to design their own stock options incentive schemes.

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