The effect of firm size, industry type and ownership structure on the relationship between firms' sustainable innovation capability and stock liquidity

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Abstract
Does the company attach importance to research and development (R&D) investment in its operations? Is stock liquidity detrimental to corporate innovation and thus damages the company’s sustainable development capabilities? We estimate the relationship between between stock liquidity and firms’ sustainable innovation capability on China’s stock market by OLS method and difference in difference (DID) method. The traditional conclusion is: the higher the stock liquidity, the weaker the enterprise’s sustainable innovation level, especially in state-owned enterprises. The DID estimation using the share-trading reform and the policy of large and small-sized non-tradable share shows that: stock liquidity will affect the sustainable innovation level of the enterprise positively. The reasons for this mechanism are the supervision mechanism in the operation of the enterprise, the effect of the balance of the ownership structure and the improvement of corporate governance. The conclusions are that the improvement of ownership concentration promotes this positive relationship, and the behavior of institutional investors does not have a significant impact. These findings also provide new insights into the relationship between corporate management and shareholder investment behavior on the level of innovation.

Keywords  Sustainable innovation capability · Ownership structure · Firm size · Firm innovation · Industry type · Stock liquidity · Difference in difference (DID)

1 Introduction
Essentially, stock liquidity is consistent with supervision and corporate governance. The behavior of stockholder will change the innovation input and strategies of enterprises.

External shocks will affect the liquidity of stocks, which in turn affects the innovative behavior of companies. Especially when the Coronavirus Disease 2019 (COVID-19) has spread over the world, it is more important to study the relationship between stock liquidity and corporate sustainable innovation.

Innovation refers to the use of new knowledge, ideas, methods and capabilities to generate unique skills and improve the competitiveness of the organization (Antunes et al. 2017; Chen et al. 2019, 2020, 2021). Kim et al. (2012) point out that innovation is divided into management innovation and technological innovation. According to the degree of innovation, technological innovation can be divided into incremental innovation and radical innovation. The characteristics of incremental innovation can be summarized as short-term innovations that are not significant, making small changes to existing technologies to meet the needs of existing customers (Tarí and García-Fernandez 2020); radical innovation (also called breakthrough innovation) means sudden change which requires the use of new knowledge to develop new products or processes that can meet the needs of new customers or emerging markets (Mikalef et al. 2019).
Stock liquidity is the foundation of capital market functions such as price discovery, information flow, and resource allocation. It also reflects the efficiency and vitality of business operations to a large extent. Stock liquidity is closely related to corporate behavioral decision-making and operating performance (Fang et al. 2014; Roosenboom et al. 2014). From the perspective of theoretical analysis, there are two mechanisms for the impact of stock liquidity on corporate R&D innovation: "incentive mechanism" and "pressure mechanism."

Existing literature has researched developed economy and finds that stock liquidity impedes firm sustainable innovation (Stein 1988; Shleifer and Summers 1998; Kyle and Vila 1991). However, is this conclusion applicable for developing countries, especially for China? Base on the data researched in the US capital market, Fang et al. (2014) find that the higher stock liquidity, the lower the firm’s sustainable innovation capability. The mechanism behind them stems from two aspects. On one hand, firms choose to invest in short-term projects to avoid hostile takeovers. On the other hand, the exit pressure of short-term institutional investors makes management give up investing in high-risk innovations. Obviously, it’s contrary to the origin of reform of non-tradable share, because the purpose of the government’s macro-policy is to improve the liquidity of stocks, then to improve the capital market’s efficiency, enhance the firm’s sustainable innovation capability and improve national competitiveness. Therefore, it is natural to support a question that “Is the conclusion of Fang consistent with the situation in China?” Wen et al. (2017) employs the data from 2006–2013 of China’s listed companies and finds that an increase in stock liquidity raises the patent’s number and the innovation efficiency of state-owned firms, while it decreases innovation significantly in private firms. Furthermore, engaging DID with quasi-natural experiments under the reform of non-tradable share and the adjustment of the stamp duty rate supports the above findings. The channels possibly include the entry of long-term and strategic institutional investors and the gradual privatization of the state-owned enterprises (SOEs). However, literature on how stock liquidity affects firm’s sustainable innovation is not sufficiently considering the inaccurate sample period, unreliable events and data types, especially when China’s capital market is facing more policy changes and uncertain factors. Thus, the researchers should select the topic “how stock liquidity affects firm’s sustainable innovation?” with more accurate sample period and more reliable methods.

From the perspective of corporate governance, the impact of stock liquidity on the firm’s sustainable innovation capability is carried out through two mechanisms: one is the strengthening of agency problems by liquidity, the other is that liquidity changes the structure of investors and strengthens the innovation capability. High stock liquidity facilitates short-term investors’ entry and exit and their pursuit of short-term gains forces corporate management to abandon innovative investment. At the same time, management tends to invest short-term project for avoiding hostile takeover threats. However, along with the diversification of the equity structure and the improvement of corporate governance, the firms strengthen their supervision of management, then enhance the enthusiasm of innovation activities.

Given the fact that the government can influence the liquidity of stocks by changing the stock market regulations and related policies, it will affect the firm’s sustainable innovation capability (Fang et al. 2014). For example, the external shocks that China’s reform of non-tradable share and large and small-sized non-tradable share policies will not only have a significant change in liquidity, but also affect the relationship between liquidity and innovation abilities remarkably. Therefore, firstly, we establish negative binomial regression estimates between liquidity and innovation capability. Secondly, under the exogenous impacts, we introduce the DID method to estimate the changes in the relationship between liquidity and sustainable innovation capability. Finally, test for the possible impact mechanisms.

Initially, stock liquidity will impede firm’s sustainable innovation capability significantly based on continuous data set. Compared with private firms, this inhibition may be weakened in the state-owned firms, which is consistent with the existing literature. However, further analysis indicates that the conclusion is unreliable, because the liquidity and innovative indicators as continuous variables may obscure the true relationship. Considering the effects of the reform of non-tradable share and large and small-sized non-tradable share policy, we give a more reliable estimate with the DID estimate results: the increase in stock liquidity enhances the firm’s sustainable innovation capability significantly. The reason is that the diversification of corporate shareholding structure, the improvement of corporate governance, and the supervision mechanism of management help to increase the enthusiasm of innovation activities. Further verification finds that enhancing the stock liquidity and the sustainable

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1 China’s reform of non-tradable share began in May 2005. By the end of 2006, the reform of the Shanghai and Shenzhen stock markets was 97%, which means that the task of the reform of non-tradable share was basically completed.

2 Large and small-sized refer to non-tradable shares, that is, restricted shares. Small-sized non-tradable share, the portion of the restricted shares that accounted for less than 5% of the total share capital, can be gradually circulated after one year of share reform; large sized non-tradable share, the portion of the restricted shares that account for more than 5% of the total share capital, can be circulated above the two years after the share reform.
innovation capability may be achieved by strengthening the ownership concentration, while the influence of institutional investors’ shareholding ratio is less.

The rest of the paper is structured as follows: Section II reviews related literature and theoretical hypothesis. In Sect. 3 we describe the sample, measurement of variables, and descriptive statistics. In Sect. 4, we show the model estimations and empirical results. Finally, we present main conclusions.

2 Literature review and theoretical hypothesis

2.1 Literature review

Although early scholars form a series of research results on stock liquidity, they mainly involve stock liquidity and asset pricing (Amihud and Mendelson 1986), capital structure (Lipson and Mortal 2009), corporate governance, capital allocation efficiency (Bhide 1993; Maug 1988; Durve et al. 2004; Edmans 2009; Cheng and Krumwiede 2010) and firm value (Amihud and Mendelson 2008; Cheung et al. 2015). While research on firm innovation focuses on the state leading innovation (Porter 1990; Grossman and Helpman 1991), firm size and innovation (Klepper 1996; Shefer and Frenkel 2003), financing constraints and R&D (Brown et al. 2011), the purchasing department (Luzzini and Ronchi 2011), value-based supply chain innovation (Munksgaard et al. 2014), ownership concentration, board independence and firm innovation (Ortega-Argilés et al. 2005; Chen et al. 2014), etc. From Stein (1988), the existing literature begin to pay attention to the impact of stock liquidity on the long-term interests (innovation). We will expand from the following two perspectives:

2.1.1 Stock liquidity impedes firm innovation

From the short-term perspective of a management, Stein (1988) and Shleifer and Summers (1998) argue that corporate management avoids hostile takeovers tending to invest short-term projects and give up long-term intangible assets. Kyle and Vila (1991) find that when the stock liquidity is higher, investors have lower entry and exit costs, which allows outsiders to cover up their intentions for acquisitions. While institutional investors are more likely to pursue short-term gains, triggering management’s short-term investment behavior and abnormal returns (Bushee 2001). Graham et al. (2005) present that managers admit to sacrificing the long-term value to smooth earnings. The measures they advocate are to make voluntary disclosures to reduce information risk and boost stock price. Atanassov (2013) show that firm’s innovation capability is declining in the region with the bill of the anti-takeover legislation, especially the one passed within two years. Fang et al. (2014) further verify the two possible channels from hostile takeovers and short-term institutional investors, which shows that stock liquidity impedes firm innovation. In summary, the reason for scholars to agree with the view that stock liquidity will impede firm innovation is that excessive stock liquidity can make management face hostile takeovers and the threat of short-term institutional investors’ withdrawal.

2.1.2 Stock liquidity enhances firm innovation

Maug (1988) believes that the higher the stock liquidity, the lower the transaction cost and the more the large-shareholders will participate in the corporate governance actively. Thus, management can concentrate on the firm’s long-term development and invest in intangible assets. Oyvind et al. (2009) find that stock liquidity can increase shareholders' enthusiasm for supervising management, especially in firms with poor performance. Coles et al. (2006) shows that the higher the stock volatility, the higher risk the management prefers to, including investment in R&D and higher financial leverage. Hall et al. (2005) verifies that the number of citations of patents affects the firm’s value positively. Tian and Wang (2014) find that the Initial public offerings (IPO) companies are more innovative with more risk preference investors. Edmans (2009) shows that high stock liquidity will make companies face the threat of withdrawal of major shareholders and improve corporate governance. Ferreira et al. (2014) believes that equity financing affects management’s innovation investment, which is positive in the private firms and negative in the state-owned firms. Aghion et al. (2013) show that institutional investors can reduce information asymmetry. Thus, corporate management will increase the innovation investment considering career, especially the threat of being removed. Wen et al. (2017) shows that the relationship between stock liquidity and innovation is different in idiosyncratic firms. For state-owned firms, stock liquidity has a positive relationship with firm’s innovation, while negative relationship in private firms. In summary, scholars who suggest that stock liquidity will enhance firm innovation believe that large shareholders can supervise effectively and institutional investors can reduce information asymmetry.

In the existing literature, the reason for the view that stock liquidity impedes firm innovation is from a short-term perspective and acquisition mechanism, while the view of stock liquidity enhancing firm innovation is due to supervision mechanism, corporate governance and investor structure. However, if the conclusions are based on continuous data, stock liquidity and corporate innovation indicators will change gradually in certain range and the conclusion may be unreliable. Therefore, firstly, we verify the relationship
between stock liquidity and firm innovation based on continuous data. Then, introduce quasi-natural experiments of external shock events for DID estimation. Finally, verify the possible impact mechanism.

2.2 Theoretical hypothesis

Given that China’s capital market started at 1990s, initial market participants prefer to chase short-term benefits. Theoretically, it is more likely that the impact of stock liquidity on firm innovation is according to the short-term perspective of management proposed by Stein (1988), that is, the short-term behavior of corporate management will impede firm’s innovation capability directly. Simultaneously, the investors behavior is more irrationality, and voting with feet will increase the probability of short-term investment projects (Daniel et al. 1998). Besides, China listed companies are general high ownership concentration, lack of equity incentives, high agent costs and deficient supervision mechanism, which will lead management to attend to purchase short-term gains rather than invest in high-risk innovations.

It is different with the stock markets in Europe and America that there are two types of firms in China: state-owned firms and private firms. For state-owned firms, about 61% of the stocks could not circulate before reform of non-tradable share. The majority shareholders who have a high proportion of shares don’t have the motivation to pursue short-term benefits. On the contrary, the private firms have smaller market sizes and more decentralized equities, so the shareholders may be inclined to short-term interests. The natural profit-seeking behavior of institutional investors will increase management’s investment in short-term projects obviously, which may reduce the expenditure of innovation. Chemmanur and Tian (2012) show that firms with anti-acquisition aims tend to have higher innovation abilities, while the state-owned firms hardly face the pressure of acquisition. The change of managers depends on the government’s administrative orders. Simultaneously, career-based considerations may be more active in investing in innovation, but the smaller size and decentralized equity of private firms will increase the probability of acquisitions. The short financial ability leads to the lack of effective anti-mergers measures. Therefore, the management is more likely to be short-term and abandon the benefits to invest in innovative high-risk projects.

However, with the implementation of reform of non-tradable share and large and small-sized non-tradable share, the rapid increase in stock liquidity may have a major impact on the firm’s innovation. The mechanisms are as follows: Firstly, the two policies have eliminated the differences between the tradable shares and the non-tradable shares. Concretely, the convergence of corporate stock prices can form a market-oriented incentive, supervision and restraint mechanism for major shareholders and management. Secondly, the improvement of the firm assessment mechanism, especially the gradual implementation of equity incentives, will enable the management to not only pay attention to the firm’s short-term interests, but also concentrate on the firm’s future development, thereby promote the investment of long-term projects such as innovation. Simultaneously, the reduction of state-owned shares and the diversification of shareholding structure not only promote firm’s development, but also enhance the rationality of investors behavior. Vice versa, voting by foot will devalue the corporate assets.

So, stock liquidity is more likely to impede firm innovation in initial stock market. Compared with private firms, the effect of stock liquidity on firm’s innovation may be weakened in state-owned firms. However, based on the continuous data with gradual changes, results will be unreliable. However, the jump-up of stock liquidity may enhance firm’s innovation with the reform of non-tradable share and large and small-sized non-tradable share.

3 Data and variables

3.1 Data and sample

We select Shanghai and Shenzhen A-share listed companies from 2002 to 2018 as the research object. The data and sample are selected as follows: the number of patents of listed companies and the shareholding ratio of institutional investors are from Wind database, the other data is from China Stock Market&Accounting Research (CSMAR) database, including the total return of assets, asset-liability ratio, total assets, main operation income, Tobin’s Q, ownership concentration, non-tradable shares, etc. Furthermore, by calculating relevant indicators, we obtain the relative effective spread, illiquidity index, industry asset-liability ratio, industry return of assets and Herfindahl index. Finally, we exclude Particular Transfer (PT) companies, Special Treatment (ST) companies, financial industry and the companies established later than 2000, eliminate the companies with missing data. Sample includes 214 listed companies, approximately 3,424 unbalanced panel data.

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3 Based on the csmax database, it is worthwhile to calculate the mean proportion of non-tradable shares of all A-share listed companies from 2000 to 2004.
3.2 Variables

3.2.1 Explained variable

Firm’s innovation capability The existing literature mainly has developed three proxies to measure firm’s innovation: patent’s numerical order, R&D investment, and total factor productivity (TFP). Because R&D investment is easily manipulated by management, it is difficult to measure firm’s innovation efficiently. Similarly, TFP is used in firm’s production, it is also difficult to measure accurately. In contrast, patents are not easily manipulated by the management, which can better measure the firm’s innovation output. Therefore, we use the patent’s numerical order to capture the firm’s innovation capability, name as PATENTs (Fang et al., 2014), the lag period for the patents in the study is 2 years.

3.2.2 Explanatory variables

Stock liquidity Following the existing literature, stock liquidity has formed three measurements, including Relative Effective Spread (RES), Turnover Rate (TURNOVER) and Illiquidity Index (ILLIQ). We refer to Fang et al. (2014) and use Relative Effective Spread (RES) capturing the stock liquidity. Considering the robustness, we also select the illiquidity index to measure stock liquidity. The formula is as follows:

Relative effective spread

\[ RES_{i,t} = \frac{1}{D} \sum_{d=1}^{D_i} \left| \frac{P_{i,d,t} - \left( BID_{i,d,t} + ASK_{i,d,t} \right)}{0.5BID_{i,d,t} + 0.5ASK_{i,d,t}} \right| \] (1)

where \( P_{i,d,t} \) is the stock’s transaction price on the \( d \)th day of the \( t \) year, \( BID_{i,d,t} \) and \( ASK_{i,d,t} \) denotes the purchase price and the selling price of the stock \( i \) at closing of the \( d \)th day in the \( t \) year, respectively. \( D_i \) defines the number of days that the stock \( i \) can observe in \( t \) years. The larger the indicator, the worse the stock liquidity.

3.2.3 Illiquidity index

\[ ILLIQ_{i,t} = 10000 \times \sum_{d=1}^{D_i} \frac{|R_{i,t,d}|}{VOL_{i,t,d}} \] (2)

where \( R_{i,t,d} \) and \( VOL_{i,t,d} \) are the stock returns and the number of transactions of the listed firm’s stock \( i \) on the \( d \)th day of the year \( t \), respectively. \( D_i \) denotes the number of trading days of the listed company \( i \) in \( t \) the year\( . \) \( |R_{i,t,d}|/VOL_{i,t,d} \) is the price change caused by a unit volume. Considering the dimension problem, we multiply the result by 10,000 as the illiquidity index. The larger the indicator, the worse the stock liquidity.

3.2.4 Control variables

Following the researchers such as Fang et al. (2014) and Wen et al. (2017), we introduce the company’s characteristic variables, industry characteristic variables and ownership characteristic variables. Specifically, the firm size (the natural logarithm of the book value of the firm’s total assets SIZE), total return on assets (ROA), asset-liability ratio (LEV), the ratio of tangible assets to total assets (TANG), firm age (LNAGE), the proportion of non-tradable shares to total stocks (NTS), financing constraints (KZ) index, investment opportunities (Q), industry return on assets (INDROA), industry asset-liability ratio (INDLEV), corporate properties (STATE), market competition intensity (HHI).

The Herfindahl index (HHI) is calculated as follows:

\[ HHI = \sum_{i=1}^{N} R_i^2 = \sum_{i=1}^{N} \left( A_i / A \right)^2; A = \sum_{i=1}^{N} A_i \] (3)

\( A_i \) represents the total operation income of a company in a certain industry in a certain year. A denotes the total operation income of all companies in a certain industry in a certain year.

The formula for KZ index defines as follows:

\[ KZ = -1.002CASHFLOW_i + 0.283Q_i + 3.139LEV_i - 39.368DIVIDENDS_i - 1.315CASHHOLDINGS_i \] (4)

\( CASHFLOW_i \) denotes the ratio of the current cash flow of the company \( i \) to the first lagged fixed assets; \( DIVIDENDS_i \) defines the ratio of the current cash dividend of the company \( i \) to the first lagged fixed assets; \( CASHHOLDINGS_i \) represents the current cash and cash equivalent of the company \( i \) to the first lagged fixed asset; \( Q_i \) and \( LEV_i \) are consistent with the data base.

3.2.5 Descriptive statistics

Considering outliers, we perform 1% winsorize processing on all variables. Table 2 shows the descriptive statistics of the full sample variables. Tables 3 and 4 show the descriptive statistics of the main variables of state-owned firms and private firms as follows.

From Table 2, there are large differences in firm patents, the median is significantly smaller than the mean, indicating that the firm’s innovation capability has great differences. For liquidity indicators, the relative effective spread is more concentrated compared with the illiquidity index. For control variables, the establishment years and the tangible assets

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4 The data is based on the final controller.
ratio are not much different. However, the asset-liability ratio and profitability show a big difference, especially the maximum ROA is positive, while minimum ROA is negative, which indicates that the firm exists extreme situation of profit and loss. Although Tobin Q has a minimum value of 0.85, the mean and median are both greater than 1.5, indicating that the firm has more investment opportunities. HHI has more differences, which denotes market competition intensity is different remarkably.

In sub-samples, compared with private firms, the patents’ number is significantly higher in state-owned firms, both the liquidity indicators are the same roughly, which indicates that the stock liquidity suppression innovation in state-owned enterprises may be weakened. Simultaneously, the size difference that is the logarithmic processing of firm total assets, between the state-owned firms and the private firms is tiny. But in fact, their actual values vary greatly, which indicates that the size may positively affect the firm’s innovation capability.

Table 1 Summary of explanatory variables

| Variable | Explanatory variables |
|----------|-----------------------|
| PATENTS  | Explanatory variable, Patent numbers Measuring firm innovation output |
| RES      |                      |
| ILLIQ    | Explanatory variable, the higher the indicator, the worse the liquidity |
| SIZE     | Explanatory variable, the higher the indicator, the worse the liquidity |
| ROA      | Control variable, the natural logarithm of the book value of the firm’s total assets, Ln (total assets) |
| LEV      | Control variable, firm profitability |
| TANG     | Control variable, the ratio of total liabilities to total assets |
| LNAGE    | Control variable, the ratio of the total tangible assets to the total assets |
| NTS      |                      |
| Q        | Control variable, the natural logarithm of the number of years from firm’s establishment to 2017, Ln (Age) |
| KZ       |                      |
| INDROA   | Control variable, the proportion of non-tradable shares to total stocks |
| INDLEV   | Control variable, industry profitability |
| HHI      | Control variable, industry asset-liability ratio |
| STATE    | Control variable, market competition intensity |
|          | Dummy variable, state-owned firms is 1, private firms is 0 |

Table 2 Descriptive statistics of full sample variables

| Variable | Number of Obs. | Mean | Median | Maximum | Minimum | Standard deviation |
|----------|---------------|------|--------|---------|---------|--------------------|
| PATENTS  | 3346          | 333.9668 | 60     | 8630    | 1       | 1088.658           |
| ILLIQ    | 3355          | 0.0156  | 0.0156 | 0.2798  | 0.0006  | 0.0526             |
| SIZE     | 3356          | 1.0004  | 1      | 1       | 1.0141  | 0.0562             |
| ROA      | 3360          | 0.0469  | 0.0469 | 0.8608  | 0.1103  | 0.1728             |
| LEV      | 3360          | 0.9722  | 0.9722 | 1       | 0.7766  | 0.0446             |
| TANG     | 3360          | 0.3446  | 0.3446 | 3.5746  | 0.0076  | 0.0819             |
| NTS      | 3360          | 0.1032  | 0.1032 | 1       | 0.0145  | 0.0459             |
| Q        | 3360          | 0.7935  | 0.7935 | 5       | 0.0129  | 0.0419             |
| KZ       | 3360          | 0.0494  | 0.0494 | 3.5746  | 0.0076  | 0.0819             |
| HHI      | 3360          | 0.0096  | 0.0096 | 0.5016  | 0.0064  | 0.0297             |
| INDROA   | 3364          | 0.3382  | 0.3382 | 0.7853  | 0.3748  | 0.450683           |
| INDLEV   | 3364          | 0.3748  | 0.3748 | 9.4588  | 9.4588  | 0.450683           |
| STATE    | 3364          | 0.3748  | 0.3748 | 9.4588  | 9.4588  | 0.450683           |

5 Grouped mean test p = 0.0000.
6 The total assets of state-owned firms are 14.5 billion yuan and the total assets of private firms are 7 billion yuan.
The effect of firm size, industry type and ownership structure on the relationship between firms’...
groups: Calculate the average turnover rate of each sample enterprise before and after the share reform, calculate the difference of the average turnover rate before and after the share reform, and sign it as $\Delta \text{TURNOVER}$; calculate the mean value of $\Delta \text{TURNOVER}$, and sign it as $M\text{TURNOVER}$. The enterprise with $M\text{TURNOVER} > M\text{TURNOVER}$ is allocated to the group with large change in liquidity, that is, the experimental group, $TREAT_{t,i} = 1$, otherwise, $TREAT_{t,i} = 0$, called the control group.

The formula for calculating the turnover rate is as follows:

$$\text{TURNOVER}_{t,i} = \sum_{d=1}^{D_{t,i}} \frac{\text{VOL}_{t,i,d}}{\text{LNS}_{t,i,d}}$$

where $\text{VOL}_{t,i,d}$, $\text{LNS}_{t,i,d}$ denote the number of transactions of the listed firm’s stock on the $d$th day at the $t$ year and the number of tradable shares, respectively. $D_{t,i}$ is the total trading days of the listed company $i$ at the $t$ year. The larger $\text{TURNOVER}_{t,i}$, the higher the liquidity.

The reform of non-tradable share began in 2005 and completed nearly 97% at the end of 2006. We build the following model with 2006 as the time point:

$$\text{PATENT}_{t,i+2} = \beta_0 + \beta_1 \text{TREAT}_{t,i} + \beta_2 \text{TIME}_{t,i} \ast \text{TREAT}_{t,i}$$

$$+ \beta_3 \text{BEFORE}_{t,i}^1 + \beta_4 \text{CURRENT}_{t,i}$$

$$+ \beta_5 \text{AFTER}_{t,i}^2$$

$$+ \epsilon_{t,i}$$

$$\text{PATENT}_{t,i+2} = \beta_0 + \beta_1 \text{TREAT}_{t,i} + \beta_2 \text{TIME}_{t,i} \ast \text{TREAT}_{t,i}$$

$$+ \beta_3 \text{TIME}_{t,i} \ast \text{TREAT}_{t,i} \ast \text{STATE}$$

$$+ \beta_4 \text{BEFORE}_{t,i}^1 + \beta_5 \text{CURRENT}_{t,i}$$

$$+ \beta_6 \text{AFTER}_{t,i}^3$$

$$+ \epsilon_{t,i}$$

where $\text{TREAT}_{t,i} = \{0, 1\}$, $\text{TREAT}_{t,i} = 0$ means firms are the control group, $\text{TREAT}_{t,i} = 1$ means firm are the experimental group, $\text{TIME}_{t,i} = \{0, 1\}$, $\text{TIME}_{t,i} = 0$ means the i firm before the reform of non-tradable share, $\text{TIME}_{t,i} = 1$ means the i firm after reform of non-tradable share, $\text{BEFORE}_{t,i}^1$, $\text{BEFORE}_{t,i}^2$, $\text{BEFORE}_{t,i}^3$, $\text{CURRENT}_{t,i}$, $\text{AFTER}_{t,i}^1$, $\text{AFTER}_{t,i}^2$, $\text{AFTER}_{t,i}^3$ represent 2002–2003, 2004, 2005 -2006, 2007, 2008–2009, 2010–2012, respectively, they are dummy variables.

### 4.2.2 Large and small-sized non-tradable share

The policy of large and small-sized non-tradable share has begun since 2007.\(^8\) We choose 2013 as a time point and build models as follows:

$$\text{INS}_{t,i}(CR) = \beta_0 + \beta_1 \text{TREAT}_{t,i} + \beta_2 \text{TIME}_{t,i} \ast \text{TREAT}_{t,i}$$

$$+ \beta_3 \text{BEFORE}_{t,i}^1 + \beta_4 \text{CURRENT}_{t,i}$$

$$+ \beta_5 \text{AFTER}_{t,i}^1$$

$$+ \beta_6 \text{AFTER}_{t,i}^2 + \epsilon_{t,i}$$

\(^8\) In 2007, 11.742 billion shares were released; in 2008, 162 billion shares were released; in 2009, 754.7 billion shares were released; in 2010,346.6 billion shares were released; in 2011,160.206 billion shares were released; in 2012, 215.728 billion shares were released; in 2013, 709.18 billion shares were released; in 2014,124.132 billion shares were released.
The effect of firm size, industry type and ownership structure on the relationship between firms’ innovation and stock liquidity is examined in this study. The reform of non-tradable share has a significant positive impact on the innovation capability in both private and state-owned firms, indicating that the policy effect caused by the reform of non-tradable share is manifested more prominent in private firms. However, in state-owned firms, the policy effects are relatively weakened, (the coefficient of \( TIME_{it} \times TREAT_{it} \) is significantly negative at the 1%). Considering the corporate property, the improvement of liquidity caused by the reform of non-tradable share is manifested more prominent in private firms. The reasons may be that the state-owned firms lead to higher agency costs and the efficiency of policy is relatively desultory, while the private firms are more flexible for responding to policy, and the increase in stock liquidity can take more efficient innovation.

In the policy of large and small-sized non-tradable share: ignoring the corporate property (third column), external shocks also significantly increase the firms’ patent number (the coefficient of \( TIME_{it} \times TREAT_{it} \) is significantly positive at the 5%), that is, the increase in stock liquidity improves the firm’s innovation capability. Considering the corporate property (fourth column), the coefficient of private firms is positive, but it is not significant. However, the increase in stock liquidity has significantly enhanced the firm’s innovation capability in state-owned firms (the coefficient of \( TIME_{it} \times TREAT_{it} \times STATE \) is significantly positive at the 5%), which is inconsistent with the policy effect of reform of non-tradable share, indicating that over time, the state-owned firms may have diversified shareholding structure, improved performance appraisal, enhanced corporate governance and market supervision mechanisms. Furthermore, the agency cost is reduced, thus the effect of large and small-sized non-tradable share is positive.

In summary, the increase in stock liquidity caused by external shocks has a significant effect on enhancing firm’s innovation capability. Considering the corporate property, in the case of the reform of non-tradable share, the effect on private firms is better than that of state-owned firms, while the policy effect of large and small-sized non-tradable share on state-owned firms is even better than that of private firms.

### 4.2.3 Mechanism analysis

In the process of the reform of non-tradable share and large and small-sized non-tradable share, which factors affect the relationship between stock liquidity and firm’s innovation? Aghion et al. (2013) believe that institutional investors can reduce information asymmetry, thereby stimulating corporate management to actively invest in innovation. Kochhar and David (2015), Chen et al. (2014) believe that increasing

### Table 6 Stock liquidity and firm’s innovation under external impact

| NBR-FE | PATENTS | Large and small-sized non-tradable share |
|--------|---------|-----------------------------------------|
|        | Reform of non-tradable share |                     |
|        | (1) | (2) | (3) | (4) |                     |
| \( TREAT_{it} \) | -0.104 | -0.084 | -0.642*** | -0.629*** |                     |
| \( \times \) | (-1.62) | (-1.32) | (-6.10) | (-5.98) |                     |
| \( TIME_{it} \times TREAT_{it} \) | 0.144*** | 0.217*** | 0.047** | 0.005 |                     |
| \( \times \) | (3.50) | (4.01) | (2.06) | (0.17) |                     |
| \( TIME_{it} \times TREAT_{it} \times STATE \) | -0.172*** | 0.079** |                     |                     |
| \( \times \) | (-2.72) | (2.35) |                     |                     |
| \( BEFORE^1_{it} \times TREAT_{it} \) | 0.864*** | 0.863*** | -0.421*** | -0.421*** |                     |
| \( \times \) | (14.11) | (14.07) | (-20.28) | (-20.31) |                     |
| \( BEFORE^{2,3}_{it} \times TREAT_{it} \) | 0.464*** | 0.465*** | -0.696*** | -0.696*** |                     |
| \( \times \) | (8.26) | (8.26) | (-36.61) | (-36.66) |                     |
| \( CURRENT_{it} \times TREAT_{it} \) | 1.224*** | 1.233*** | -0.279*** | -0.280*** |                     |
| \( \times \) | (23.61) | (23.72) | (-16.12) | (-16.18) |                     |
| \( AFTER^{1,5,6}_{it} \times TREAT_{it} \) | 1.575*** | 1.594*** | -0.142*** | -0.142*** |                     |
| \( \times \) | (27.85) | (28.05) | (-8.49) | (-8.53) |                     |
| \( AFTER^{2,3}_{it} \times TREAT_{it} \) | 1.946*** | 0.033 |                     |                     |
| \( \times \) | (37.92) | (-0.82) |                     |                     |
| \( AFTER^{5,6}_{it} \times TREAT_{it} \) | 2.486*** | 2.520** |                     |                     |
| \( \times \) | (50.26) | (50.57) |                     |                     |
| Constant | 0.118*** | 0.101* | 4.130*** | 4.130*** |                     |
| \( \times \) | (2.13) | (1.84) | (48.95) | (48.96) |                     |

Notes: *** represents the significance level is 1%, ** represents the significance level is 5%, * represents the significance level is 10%. The t-statistics of the regression coefficients are in parentheses.

\[
PATENT_{it} = \beta_0 + \beta_1 TREAT_{it} + \beta_2 TIME_{it} \times TREAT_{it} + \beta_3 TIME_{it} \times TREAT_{it} \times STATE + \beta_4 TIME_{it} \times TREAT_{it} \times BEFORE_{it} + \beta_5 TIME_{it} \times TREAT_{it} \times CURRENT_{it} + \beta_6 TIME_{it} \times TREAT_{it} \times AFTER_{it} + \epsilon_{it} \tag{10}
\]
ownership concentration improves innovation performance, which can direct necessary resources for innovation. Since the reform of non-tradable share, China’s institutional investors have become more active and the change of shareholding structure is constantly. Then, does stock liquidity affect firm’s innovation by changing institutional investors’ shareholding ratio and the ownership concentration? We verify the possibilities as follows:

Considering the fact that the institutional investors’ shareholding ratio (INS) and ownership concentration (CR) range between [0, 1], we construct the regression equation by using the stochastic effect of the censored regression model (TOBIT model)\(^ {10}\):

\[
INS_{i,t}(CR_{i,t}) = \beta_0 + \beta_1 TREAT_{i,t} + \beta_2 TIME_{i,t} + \beta_4 \text{TREAT}_{i,t} + \beta_5 \text{BEFORE}_{1,t} + \beta_6 \text{BEFORE}_{2,3,t} + \beta_7 \text{CURRENT}_{i,t} + \beta_8 \text{AFTER}_{1,t} + \beta_9 \text{AFTER}_{2,3,t} + \beta_{10} \text{AFTER}_{4,5,6,t} + \epsilon_{i,t}
\]

For the influence of institutional investors’ shareholding ratio (INS) and ownership concentration (CR) on the firm’s innovation capability, we employ the negative binomial regression. The model is constructed as follows:

\[
PATENT_{i,t+2} = \beta_0 + \beta_1 TREAT_{i,t} + \beta_2 TIME_{i,t} + \beta_3 \text{TREAT}_{i,t} + \beta_4 \text{INS}_{i,t}(CR_{i,t}) + \beta_5 \text{BEFORE}_{1,t} + \beta_6 \text{BEFORE}_{2,3,t} + \beta_7 \text{CURRENT}_{i,t} + \beta_8 \text{AFTER}_{1,t} + \beta_9 \text{AFTER}_{2,3,t} + \beta_{10} \text{AFTER}_{4,5,6,t} + \epsilon_{i,t}
\]

In Table 7, the first column is the impact of the reform of non-tradable share, the results show that the policy significantly reduces the institutional investors’ shareholding ratio (the coefficient of \(TIME_{i,t} \ast TREAT_{i,t}\) is significantly negative at the 1%). But the results of first column and second column show that there is no significant relationship between the institutional investors’ shareholding ratio and the improvement of firm’s innovation capability. So, it is concluded that the institutional investors’ shareholding ratio isn’t the reason that stock liquidity would enhance the firm’s innovation capability, which is inconsistent with the conclusion of Fang et al. (2014). After the reform of non-tradable share, the increase in stock liquidity may attract more private investors rather than institutional investors. The difference between the tradable shares and non-tradable shares is eliminated gradually. Thus, the prices of the non-tradable shares will be consistent with the tradable shares, and incentive and restraint mechanisms will be promoted. The results of the third column show that the impact of the reform of non-tradable share has significantly reduced the firm’s ownership concentration (the coefficient of \(TIME_{i,t} \ast TREAT_{i,t}\) is significantly negative at the 1%), while in the fourth column, the ownership concentration has a significantly positive impact on the improvement of firm’s innovation capability, which indicates that there is a mediation effect between stock liquidity and firm’s innovation. The improvement of liquidity will enhance the firm’s innovation capability by changing the ownership concentration.

In Table 8, the first column shows the inconsistency with the reform of non-tradable share. The impact of the large and small-sized non-tradable share has significantly increased the institutional investors’ shareholding ratio (the coefficient of \(TIME_{i,t} \ast TREAT_{i,t}\) is significantly positive at

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9 The sum of the shareholding ratios of the firm’s top three shareholders.

10 The LR test results suggest that there is an individual effect, so panel Tobit regression with random effects should be used.
The effect of firm size, industry type and ownership structure on the relationship between firms’ innovation capability and stock liquidity will enhance the firm’s innovation capability by strengthening the ownership concentration.

In summary, the external shocks: reform of non-tradable share and large and small-sized non-tradable share rapidly increase stock liquidity and thus enhance the firm’s innovation capability by changing the ownership concentration, while the influence of institutional investors’ shareholding ratio is insignificant.

## 5 Conclusions

From the perspective of business strategy and stock market signals, we examine the relationship between stock liquidity and firm’s innovation using the panel data. The results of the panel data are consistent with the premier researchers. However, further analysis indicates that the conclusion is unreliable. The reform of non-tradable share and large and small-sized non-tradable share policy give a more reliable estimate with the DID estimate results. The increase in stock liquidity significantly enhances the firm’s innovation capability. The reason is that the diversification of corporate shareholding structure, the improvement of corporate governance, and the supervision mechanism of management help to increase the enthusiasm of innovation activities. Further verification shows that enhancing the stock liquidity and the innovation capability may be achieved by strengthening the ownership concentration, while the influence of institutional investors’ shareholding ratio is insignificant.

For all companies, the reform of non-tradable share has reduced the institutional investors’ shareholding ratio and ownership concentration, which will enhance the firm’s innovation capability. The improvement of the assessment mechanism is the key factor. The large and small-sized non-tradable share has increased the institutional investors’ shareholding ratio and ownership concentration, furthermore, enhanced the firm’s innovation capability. The ownership concentration is the crucial factor.

The conclusion that stock liquidity of listed companies influences corporate innovation implies that companies should devote themselves to information disclosure, improving corporate stock liquidity by using financing and investment information, and ultimately affect investors’ long-term innovation preference, so as to improve corporate innovation ability.

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### Authors’ contributions
Liang Tang and Jiali Liu designed research, performed research, Zhen Gu and Qi Zhang analyzed data, and wrote the paper.

### Data availability
Data available on request from the authors.
Declarations

Conflicts of interest The authors declared that they have no conflicts of interest to this work.

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