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Stock liquidity and investment efficiency: Evidence from the split-share structure reform in China

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ABSTRACT

Using China's split-share structure reform, we examined the effect of stock liquidity on investment efficiency. We found that enhanced stock liquidity results in more efficient investments and the effect is much more pronounced for under-investing firms than for over-investing firms. Additionally, we found that an increase in institutional ownership and price efficiency generated by a change in stock liquidity is positively associated with a reduction in under-investment. Thus, these findings suggest that under-investing firms with liquid stocks have more informed investors and face greater pressure to select an optimal investment level in the post-reform period.

1. Introduction

A growing number of studies have investigated how stock markets affect real corporate decisions, such as investment decisions (e.g., Edmans et al., 2012, 2015; Goldstein et al., 2013; Dow et al., 2017; Edmans et al., 2017).[1] In particular, it has been reported that firms with more liquid stocks, i.e., stocks which can be traded in reasonable quantities without incurring large trading costs, enjoy lower equity underwriting fees (Butler et al., 2005) and a lower cost of debt (Chen et al., 2020; Francis et al., 2016; Cheung et al., 2021). Thus, it may follow that increased stock liquidity can expand investment opportunities by lowering external financing costs. Additionally, by facilitating price discovery (Kerr et al., 2019) and providing feedback to managers (Bond et al., 2012), increased stock liquidity can guide managers to make better investment and financing decisions.

However, previous studies offer various explanations for why firms invest inefficiently, including those based on agency costs, financial constraints, and information asymmetry. For example, shirking managers who enjoy quiet lives can cause under-investment problems in their firms (Bertrand and Mullainathan, 2003). However, firms with higher free cash flows are subject to more severe over-investment problems, which is consistent with agency cost explanations (Richardson, 2006). Chen et al. (2011) found that government

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[1] Bond et al. (2012) provided a comprehensive survey of literature examining the real effects of financial markets.

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intervention distorts investment behavior and lowers investment efficiency.[2] Studies have identified various factors that can mitigate investment inefficiency, such as governance structure (Richardson, 2006), financial reporting quality (Biddle et al., 2009; Gomariz and Ballesta, 2014), accounting conservatism (Lara et al., 2016), internal capital markets (Hovakimian, 2011), and the expertise and quality of analysts following a firm (Chen et al., 2017). The above discussion presents an array of potentially countervailing factors. Therefore, whether stock liquidity, an important aspect of the stock market, influences corporate investment efficiency remains an interesting empirical question.

Using China as the study setting, we examined whether a firm's investment efficiency is affected by its stock liquidity. Higher investment efficiency can have real consequences for the economy by allocating capital optimally (and, in turn, labor) and by ensuring that firms neither ignore profitable investment opportunities nor invest excessively in unprofitable projects. To the extent that stock liquidity leads to efficient investment decisions, liquid stock markets can mitigate the adverse real effects arising from business cycle fluctuations such as industry-wide or nation-wide under- or over-investment problems. Accordingly, researchers and policymakers should investigate the effects of stock liquidity on investment efficiency and economic mechanisms.

To improve our understanding of this important, plausibly causal relationship between stock liquidity and investment efficiency, and the associated mechanisms that are exclusive to a developing country like China, we aim to obtain causal estimates by exploiting the 2005 split-share structure reform in China, which significantly affected stock liquidity. Thus, our study makes a tangible offer for an important addressable gap in the literature.

An empirical examination of the directional effect of stock liquidity on investment efficiency is intriguing, mainly because theoretical predictions are not unanimous about the *ex ante* relationship. Some studies argue that stock liquidity is a channel through which financial disclosure increases investment efficiency. These studies have established that high-quality accounting information can mitigate asymmetric information among investors and improve stock liquidity (Verrecchia, 2001), which is consistent with empirical studies that find a positive relationship between the two (e.g., Healy et al., 1999; Leuz and Verrecchia, 1999). Thus, superior information environments help lower the cost of capital by reducing adverse selection costs and improving access to external capital (e.g., Östberg, 2006), which can increase a firm's investment efficiency (Stoughton et al., 2017), especially when it is financially constrained.

However, higher stock liquidity can directly affect governance environments by reducing the exit costs for unhappy shareholders (Bhide, 1993) and lowering the incentives of large blockholders to invest in the firm (Edmans et al., 2013).[3] This can weaken the role of governance in disciplining managers regarding their investment choices, thereby allowing them to invest inefficiently. Thus, unpacking the direct link between stock liquidity and investment efficiency and deepen our understanding and help policymakers shape effective financial regulations to improve real outcomes.

In summary, our baseline hypothesis is that high stock liquidity improves investment efficiency. This improvement happens through various potential channels, including: 1) through a better functioning feedback effect, i.e., stock prices convey valuable information to managers and help them improve corporate decision making (Goldstein and Guembel, 2008; Dow et al., 2017); 2) by increasing blockholders' incentives to monitor due to the quick translation of their efforts into observable price changes (Holmström and Tirole, 1993; Faure-Grimaud and Gromb, 2004); and 3) by relaxing financing constraints and improving access to both internal and external finance (Butler et al., 2005; Chen et al., 2020; Francis et al., 2016; Cheung et al., 2021; Michaely and Qian, 2022).

However, we also argue that substantial heterogeneity exists in how stock liquidity affects investment efficiency according to a firm's propensity to under-invest (or over-invest). The underlying causes and environmental conditions leading to under- and over-investment problems are remarkably diverse, resulting in varying consequences for stock liquidity. Accordingly, we entertained an asymmetric effect of stock liquidity—more specifically, we further hypothesized that the role of liquid stock markets in mitigating over-investment problems was weaker for several reasons. First, firms with more free cash flow and a lower level of blockholder monitoring show a higher propensity to over-invest. High stock liquidity, by facilitating the easier exit of blockholders and lowering the price impact of selling, leads to weaker intervention by activists. Second, higher levels of speculative trading and short-sale constraints can affect under- and over-investment problems differently. Such institutional features in China, along with the close linkage between executive career prospects and political capital, may even reward managers for their over-investing behavior. At the same time, liquid stock markets provide positive feedback to under-investing managers on their new project announcements, thus potentially leading to asymmetric effects of stock liquidity.

We used a sample of publicly listed Chinese companies because they provide an excellent study setting for examining the relationship between stock liquidity and investment efficiency for two reasons. First, a combination of short-sale constraints and weaker investor protection allows for much larger deviations from optimal investment decisions (Guariglia and Yang, 2016), giving more meaningful prominence to and concern about investment inefficiency. Second, as shown by prior studies, such as Liao et al. (2014), the split-share structure reform in China, as part of the second wave of privatization, increased the supply of tradable shares and thus provided us with an ideal setting to study the effect of stock liquidity on investment efficiency. Thus, we examined whether there is a causal link between an increase in stock liquidity and investment efficiency by exploiting the 2005 split-share structure reform (e.g., Campello et al., 2014) as a quasi-natural experiment.

Our findings support the hypothesis that stock liquidity has a positive causal effect on investment efficiency in firms prone to under-

[2] Investment efficiency is defined as the degree to which the actual investment level is close to the optimal investment level, namely, an investment level in which all and only positive net present value (NPV) investment projects are undertaken (Biddle et al., 2009).

[3] For example, Chang et al. (2017) found that an increase in stock liquidity facilitated managers' bad news hoarding, resulting in an increase in future stock price crash risk.

investment. A one-standard-deviation increase in stock liquidity reduces under-investment by 8.3%, relative to the subsample mean. By contrast, we found that stock liquidity does not mitigate over-investment problems. Our baseline findings are robust to alternative measures of stock liquidity, alternative definitions of investment efficiency, a range of model specifications, and a quasi-natural experiment based on split-share structure reform. Using the split-share structure reform, we found that under-investing firms that witnessed greater increases in stock liquidity around the reform increased their investment efficiency by 58.14% (a 2.5 percentage points increase from the sample mean of 0.043). Furthermore, when we divided our stock liquidity measure into positive and negative return days, we found that stock liquidity during negative return days had a more pronounced effect on the investment efficiency of under-investing firms. Brennan et al. (2013) found that only liquidity on down days (i.e., negative return days) commands a return premium. In equilibrium, higher stock liquidity is associated with lower capital costs because investors are less exposed to illiquidity risk. Thus, when accompanied by higher stock liquidity, downward price movements significantly reduce the capital costs of under-investing firms and facilitate a higher investment rate.

We conducted further tests to understand the channels through which enhanced stock liquidity reduces under-investment problems. We found that the reform coincided with an increase in institutional ownership and price efficiency. Taken together, these findings suggest that under-investing firms with liquid stocks have more informed investors and face greater pressure to select an optimal investment level in the post-reform period, thereby allowing them to undertake more investment projects. We also found evidence that enhanced stock liquidity improves access to internal and external financing and relaxes financing constraints. However, changes in financing constraints, retained earnings, or external financing brought about by liquidity changes cannot account for improvements in investment efficiency. In summary, these results suggest that higher stock liquidity provides stronger motivation and pressure for under-investing firms to improve their investment efficiency, whereas over-investing firms are largely unaffected.

A unique characteristic of Chinese stock markets is the significant role played by the Chinese government in business activities through its majority ownership in state-owned enterprises (SOEs). Chen et al. (2011) found that SOEs invest more efficiently than other private enterprises. To understand how stock liquidity affects these dynamics, we examined if our findings varied when the controlling owner was the state and found that our results were present in both groups of under-investing firms. In addition, SOEs' over-investment is sensitive to stock liquidity. These findings suggest that stock liquidity improves under-investing SOEs' investment and that reforms such as the split-share structure reform may have been targeted at these firms, subsequently eliciting a positive response.

This study contributes to existing literature in several ways. First, we provide new evidence on the effect of financial markets on real corporate decisions. Using theories on the feedback effect and incentives, we argue that stock liquidity modifies the investment efficiency of under-investing firms, and therefore, has real consequences for the economy. As such, our evidence adds to the growing body of literature (Morck et al., 1990; Dow and Gorton, 1997; Shleifer and Vishny, 2003; Goldstein and Guembel, 2008; Bond et al., 2012). Notably, studies such as Fang et al. (2014) argued that increased stock liquidity, by increasing hostile takeover risk and the proportion of non-dedicated institutional ownership, induced managers to make myopic investment decisions (e.g., under-investment in innovation). Our findings challenge this view, especially for under-investing firms, and suggest that institutional owners exhibit varied preferences for tangible fixed assets over risky innovations (Fang et al., 2014). Moreover, our evidence of the positive effect of stock liquidity on investment efficiency in under-investing firms is consistent with a concurrent study by Amihud and Levi (2023), who found that managers of illiquid firms make capital-constrained investment decisions, such as over-investing in labor and under-investing in fixed assets. We also add to the growing literature on the factors that influence firms' investment efficiency (Biddle et al., 2009; Chen et al., 2011; Gomariz and Ballesta, 2014; Lara et al., 2016; Chen et al., 2017; Stoughton et al., 2017). Moreover, our study extends the work of Polk and Sapienza (2008) and Bakke and Whited (2010) on how stock market mispricing and stock prices affect firm-level investment.

The remainder of this paper is organized as follows. Section 2 reviews the literature and develops the testable hypotheses. Section 3 describes the empirical framework. In Sections 4 and 5, we present the empirical findings and discuss additional test results. Finally, we conclude the paper in Section 6.

2. Related literature and the development of hypotheses

2.1. Effect of stock liquidity on investment efficiency

Various studies provide direct or indirect theoretical arguments that enhancing stock liquidity improves corporate investment efficiency (i.e., reduces under-investment and/or over-investment). Although there may be other potential channels, most of these arguments are largely related to three: improved corporate governance, an enhanced feedback effect, and relaxed financing constraints. We elaborate on them below.

2.1.1. Improved corporate governance channel

Corporate governance plays an important role in improving a firm's investment decisions. Institutional owners with large blocks of shares tend to have strong incentives to monitor firms, create independent boards of directors, and, generally, actively encourage firms to make more efficient investment decisions. Institutional investors can affect company policies through many avenues, such as shareholder voting, trading on private information (Edmans, 2009), or informal communication with management. Additionally, when institutional owners do not agree with management decisions, they can sell or threaten to sell their entire stake (i.e., they use an "exit" option). Previous studies (e.g., Hartzell and Starks, 2003; Edmans, 2014) have shown that when managerial compensation is closely tied to shareholder returns, such exit behavior can discipline managers. Somewhat paradoxically, however, when stock liquidity increases because of a lower price impact, large trades aimed at disciplining management render the exit option a less

effective strategy.

Most notably, when distinguishing between under- and over-investing firms, governance lapses differ in nature. Under-investing firms often do not pursue value-increasing projects because of inexperience, lack of capital, or poor management strategies. By contrast, over-investing firms have a proclivity to pursue value-decreasing projects due to managerial optimism or overconfidence. Therefore, institutional ownership can play different roles in mitigating contrasting firm behaviors. In the former case, *voice* or *activist* strategies can be quite effective in encouraging management to undertake more investments, whereas in the latter case, only exit strategies have the potential to influence managerial decisions. Any increase in stock liquidity further weakens exit strategies, thereby weakening the effect of institutional ownership on the reduction of over-investment. However, voice strategies have become more plausible and effective in reducing under-investment because of the positive spillover of liquidity on the cost of capital and access to finance (Amihud and Mendelson, 1989; Butler et al., 2005).

Therefore, by drawing together the preceding strands, we argue that an increase in stock liquidity generally increases institutional ownership by lowering monitoring costs. However, the effectiveness of monitoring depends on the seriousness of existing governance lapses, and the impact of institutional forces is asymmetric along the demarcation of under- and over-investing, based on the reasoning above. Accordingly, we predict that governance executed through institutional ownership will likely be more successful in mitigating under-investment than over-investment.

2.1.2. Enhanced feedback effect channel

Proponents of the feedback effect suggest that managers learn from stock prices to make informed corporate decisions. Trading in the secondary market provides valuable information to managers because it incorporates consensus opinions about a firm's future economic growth, industry conditions, and investment opportunities. At the one extreme, trading without new information can influence managers. For example, when speculators invest without new information, they are likely to increase prices. Managers may regard the observed higher stock price as a validation of their investments, which could induce a greater propensity to over-invest (Goldstein and Guembel, 2008). At the other extreme, under perfect feedback, informed traders may weigh the prospect that their large trades will affect firm decisions and therefore use amplified trading behavior to signal their investment choices to managers (Khanna and Sonti, 2004).

The feedback theory also suggests that a firm's investments may be highly sensitive to stock liquidity. Dow et al. (2017) argued that traders' incentives to produce information about a firm's investment opportunities depend on the *ex ante* probability of the firm making new investments. A minor shock to the fundamentals of a firm that lowers the likelihood of investment can halt information production, leading to a large discontinuous drop in investment disproportionate to the shock. The feedback theory also suggests that managers' attention to stock prices increases with liquidity because, at higher levels of liquidity, the precision of the feedback signal from the market is higher. To the extent that enhanced stock liquidity lowers speculators' information costs and strengthens their incentives to produce information, we predict that stock liquidity enhances investment efficiency.

Specifically, higher stock liquidity increases stock price informational efficiency. By attracting more short-term traders and institutional investors, higher stock liquidity increases the demand for stock-specific information. This encourages managers to disclose more information to the market, thereby making stock prices more informative (Boehmer and Kelley, 2009; Brogaard et al., 2017). Investors often possess better information about future growth opportunities for the industry, economy, and country than the manager's private information. Managers can obtain feedback on their investment choices and invest optimally by learning from stock prices. Higher stock liquidity can enhance this feedback effect by increasing informational efficiency, thereby increasing investment efficiency. However, the enhanced feedback effect channel makes similar predictions for both over- and under-investing firms regarding investment efficiency.

2.1.3. Relaxed financing constraints channel

Many prior studies, such as Fazzari et al. (1988) have shown that financially constrained firms or firms with limited access to internal and external finance are more likely to under-invest. Michaely and Qian (2022) have also shown that liquidity improvement following the split-share structure reform induced Chinese firms to reduce dividend payouts and increase their retained earnings. As retained earnings are a crucial source of financing for Chinese firms (Allen et al., 2005; Allen et al., 2019), we expect enhanced stock liquidity to significantly reduce Chinese firms' under-investment problems by increasing retained earnings. Firms with more liquid stocks have also been reported to enjoy lower equity underwriting fees (Butler et al., 2005) and a lower cost of debt (Chen et al., 2020; Francis et al., 2016; Cheung et al., 2021). Thus, it may follow that increased stock liquidity can expand investment opportunities by lowering external financing costs. Therefore, we posit that enhanced stock liquidity relaxes financing constraints and improves access to internal and external financing, thereby reducing under-investment problems.

Collectively, the theoretical arguments related to the above-mentioned three channels (i.e., improved corporate governance, enhanced feedback effect, and relaxed financing constraints) lead to a core empirical prediction: ***Improved stock liquidity leads to more efficient investment.***

2.2. Asymmetry in the effect of stock liquidity on under- and over-investing firms

The effect of stock liquidity on investment efficiency is not similar for under- and over-investment problems because their underlying causes and enabling environments are starkly different (Edmans et al., 2015). For example, a weak governance mechanism, speculative trading, and short-sale constraints allow over-investment to thrive, while it is plausible (and even likely) that all these factors have opposite or weaker effects on under-investment behavior.

Over-investment has several antecedents. Managers of firms with large free cash flows show a greater propensity to engage in wasteful expenditure (Jensen, 1986; Stulz, 1990). In addition, when external monitoring by activist institutions or the takeover market is weak, such over-investment can persist (Gompers et al., 2003; Larcker et al., 2007). While stock liquidity lowers monitoring costs by facilitating block formation and amplifying the takeover threat, it can also decrease the costs of exit (selling), thereby weakening the incentives of external monitors (Appel et al., 2016; Schmidt and Fahlenbrach, 2017). As monitoring costs increase with the seriousness of governance lapses, institutional investors intervene only in circumstances where monitoring is less costly; that is, they choose to exit firms with over-investment problems while continuing to monitor firms with under-investment problems. An increase in stock liquidity increases market depth; however, paradoxically, this can provide a false sense of validation to managers of over-investing firms. From another perspective, positive feedback trading related to investment announcements of under-investing firms can encourage such managers to invest further.

The role of stock liquidity in emerging markets, such as China, in mitigating over-investment is further curtailed through the close linkage between career prospects and political capital, thus encouraging managers to pursue secondary objectives, such as increasing firm size and scope, and helping achieve GDP policy or regional or social development objectives (Chen et al., 2011). Given these opposing arguments, the effect of stock liquidity on over-investment is *ex ante* unclear and remains an open empirical question.

3. Empirical framework

3.1. Sample selection

Our sample consists of 11,305 firm-year observations of non-financial Chinese firms listed on the Shanghai and Shenzhen stock exchanges for the period 2002–2016. We excluded firms with incomplete information from the China Stock Market & Accounting Research (CSMAR), and Wind databases. We also excluded firms relegated to the special treatment (ST) category by the China Securities Regulatory Commission (CSRC) owing to operational losses over two consecutive years or accounting irregularities. We obtained daily stock returns and annual financial statement data from CSMAR and supplemented them with institutional equity ownership data from the Wind database. We used the Thomson Reuters Securities Data Company (SDC) database to obtain data on mergers and acquisitions (M&A) involving Chinese firms.

3.2. Variable definitions

3.2.1. Measures of stock liquidity

We employed Amihud's (2002) illiquidity measure to determine the degree of illiquidity of stocks. The Amihud illiquidity measure has been widely used in prior studies and performs well in capturing the price impact of trading (Acharya and Pedersen, 2005; Goyenko et al., 2009). To reduce the skewness of the Amihud measure, we applied a log transformation (Edmans et al., 2013) and, for ease of interpretation, we multiplied by −1 to ensure that our measure represents liquidity rather than illiquidity. Hence, our liquidity measure is defined as follows:

$$LIQ_{i,t} = -log\left(1+\frac{1}{D_{i,t}}\sum_{d=1}^{D_{i,t}}\frac{|R_{i,d,t}|}{Yvol_{i,d,t}}\right), \quad (1)$$

where $R_{i,d,t}$ is the daily return on stock i in year t and $Yvol_{i,d,t}$ is the daily CNY volume in millions for stock i in year t.

To overcome the concern that the Amihud measure might capture trading volume rather than liquidity (Lou and Shu, 2017), following Corwin and Schultz (2012) we used an alternative stock liquidity measure, *LIQ_CS*, based on *High-Low spread* which precisely captures the cost of trading immediacy or the price impact of large trades.[4] In addition, to understand whether stock liquidity associated with positive versus negative price movements (e.g., Brennan et al., 2013) drives our findings, we employed the Amihud illiquidity measure, calculated separately on positive and negative return days. We applied the transformations used to obtain our main liquidity measure to obtain the alternative liquidity proxies. The definitions of all the variables, including the liquidity measures, are provided in Table 1.

3.2.2. Measures of investment efficiency

Following Biddle et al. (2009), we computed the magnitude of investment efficiency $INVEFF_{i,t}$ as minus one times the absolute value of the residuals, which are obtained from the following *industry-year* cross-sectional regressions of investment on lagged sales growth:

[4] In additional tests, we used alternative measures of stock liquidity, namely, turnover and trading volume, whose construction and findings are discussed in Section 5.2.

Table 1
Definition of variables.

Variables	Definitions
Investment-related measures	
INV	Rate of investment measured as the change in net fixed assets scaled by lagged total assets
INVEFF	Computed as minus one times the absolute value of the residuals from industry-year cross-sectional regressions of *INV* on lagged sales growth
Stock liquidity measure	
LIQ	*–log(1 + Amihud)* where *Amihud* is Amihud's (2002) price impact measure as defined in Section 3.2.1.
LIQ_CS	*–log(High-Low spread)* where *High-Low spread* is Corwin and Schultz's (2012) measure where the spread is estimated as the annual average of high-low spread over all overlapping two-day periods in the year
DOWN_LIQ	$-log(1 + Amihud^{Down})$ where $Amihud^{Down}$ is Amihud's (2002) price impact measure computed using days with negative returns only (Brennan et al., 2013)
UP_LIQ	$-log(1 + Amihud^{Up})$ where $Amihud^{Up}$ is Amihud's (2002) price impact measure computed using days with positive returns only (Brennan et al., 2013)
Control variables	
LOGASSET	Logarithm of book value of total assets
Q	Ratio of market value of total assets to book total assets
SD_CFO	Standard deviation of the ratio of cash flow from operations to total assets from years *t*–5 to *t*–1
SD_SALE	Standard deviation of sales to total assets from years *t*–5 to *t*–1
SD_INV	Standard deviation of *INV* from years *t*–5 to *t*–1
Z	Altman's Z score computed as ((3.3 × [*pretax income*] + [*sales*] + 1.4 × [*retained earnings*] + 1.2 × ([*current assets*]–[*current liabilities*])/[*total assets*]).
TANG	Ratio of property, plant, and equipment to book total assets
KSTR	Ratio of long-term debt to the sum of long-term debt and the market value of equity
IND_KSTR	Mean *KSTR* for firms in the same industry
CFO_SALE	Ratio of cash flows from operations (*CFO*) to sales
SLACK	Ratio of cash to property, plant, and equipment (*PPE*)
DIV	An indicator variable that takes the value of one if the firm paid a dividend and zero otherwise
AGE	Number of years the firm's shares have traded in the secondary market
OPERATINGCYCLE	Natural logarithm of 360 × ([*receivables*]/[*sales*] + [*inventories*]/[*COGS*])
LOSS	An indicator variable that takes the value of one if net income is negative and zero otherwise
CASH	Ratio of cash and cash equivalents to book total assets
ANALYSTS	Number of analysts who have published at least one report for a firm in a given year
SOE	An indicator variable that takes the value of one if the firm is a state-owned enterprise (i.e., the controlling shareholder is the government or its related entities) and zero otherwise
CEO_DUAL	An indicator variable that takes the value of one if the CEO of a firm is their chairman as well and zero otherwise

This table reports the definition of investment-related measures, stock liquidity measure, and control variables used in this study.

$$INV_{i,t} = \alpha_0 + \alpha_1 SalesGrowth_{i,t-1} + \epsilon_{i,t}, \tag{2}$$

where $INV_{i,t}$ is the change in net fixed assets divided by the lagged total assets.[5] Alternatively, to control for differences in standard deviations across industry years, we computed the magnitude of investment efficiency as minus one times the absolute value of the residuals divided by the standard deviation of the residuals. Using the sign of the residuals, we identified under-investing (over-investing) firms as those with negative (positive) residuals before taking the absolute value and multiplying it by minus one.[6]

Chen et al. (2018) argued that it is problematic to obtain inferences when residuals are used as dependent variables. This can result in systematically biased coefficients and standard errors. Therefore, following Chen et al. (2018), we implemented two solutions to address this concern. The first solution was to estimate the coefficients for all model regressors in a single-stage regression, including the interactions of the first-stage regressors with year and industry when the first-stage residuals are estimated by industry year. The second was to estimate a single-stage model after including first-stage regressors in the second stage.

3.2.3. Other measures

To examine the underlying channels through which stock liquidity affects investment efficiency, we tested whether it influences institutional ownership, price efficiency, and financing constraints. To examine the corporate governance channel, we used the proportion of institutional ownership, which is computed as the proportion of shares held by institutional investors, such as mutual funds, securities companies, qualified foreign institutional investors, insurers, banks, and pension funds. To test the feedback effect

[5] As robustness tests, we computed the magnitude of investment efficiency as minus one multiplied by the absolute value of the residuals from the industry-year cross-sectional regressions of investment on Tobin's Q (lagged), the inverse of total assets (lagged), and operating cash flows to total assets (contemporaneous). Our main results were very similar when the new investment efficiency measure was used. One advantage of using Tobin's Q is that it contains forward-looking information about a firm's future investment opportunities. However, a commonly used proxy, i.e., average Q, is subject to serious measurement errors. Thus, we reported the results based on Biddle et al. (2009) approach.

[6] We also repeated our tests with alternative definitions of $INV_{i,t}$ as discussed in Section 5.2.

channel, we used a measure of price efficiency, which computes the informational efficiency of stock prices as the first-order autocorrelation of weekly stock returns multiplied by −1. A smaller autocorrelation indicates that stock returns are less predictable and, thus, stock prices are more efficient (Brogaard et al., 2017). To test the financing constraint channel, we used the financing constraint measure proposed by Hadlock and Pierce (2010), the HP index. The HP index was computed as $-0.737Size + 0.043Size^2 - 0.040Age$, where *Size* is the natural logarithm of total assets and *Age* is the number of years elapsed since the listing date. To further examine the financing constraint channel, we used retained earnings and external financing measures. The retained earnings measure is computed as the amount of retained earnings on the balance sheet divided by the total book assets at the beginning of the fiscal year. The external financing measure was computed as the total external financing amount (i.e., proceeds from obtaining bank loans and issuing bonds and stocks) divided by total book assets at the beginning of the year.

3.3. Summary statistics

Tables 1 and 2 present the definitions and summary statistics of the key variables, respectively.[7] Univariate comparisons of firms with high and low liquidity suggest that firms with more liquid shares tend to have significantly higher investment rates and make more efficient investment decisions. The *t*-tests and Wilcoxon rank-sum tests suggest that the differences in both the investment rate and investment efficiency are statistically significant at the 1% level. Overall, the summary statistics of the control variables used in this study are similar to those of other comparable studies examining Chinese firms (Li et al., 2011; Liao et al., 2014). Additionally, the other variables differ significantly between high- and low-liquidity firms.

3.4. Research design

3.4.1. Regression models

We employed the following empirical approach to examine the effect of stock liquidity on investment efficiency: first, following the empirical framework of Biddle et al. (2009), we examined the conditional relationship between stock liquidity and investment efficiency. Using a pooled ordinary least squares (OLS) specification with investment as the dependent variable, we interacted a measure of stock liquidity with *ex ante* proxies for a firm's under-investment propensity, while controlling for various firm characteristics and governance measures. For a more direct test of the degree of investment inefficiency, we examined the effect of stock liquidity on the absolute value of the deviation from the expected investment rate using a pooled OLS specification. In addition, we examined the role of stock liquidity on investment–Q sensitivity (Chen et al., 2007) using our sample firms. However, these regression frameworks are subject to concerns about endogeneity. For example, firms with better access to equity markets can have higher stock liquidity because of frequent equity issuances, which increase their outstanding shares (e.g., Calomiris et al., 2019). Simultaneously, these firms can exhibit a greater propensity to over-invest because of excess cash from previous equity issuances. This leads to a spurious negative correlation between stock liquidity and investment efficiency. Additionally, unobservable omitted variables such as corporate governance can influence both investment efficiency and stock liquidity.

3.4.2. Addressing endogeneity concerns using the 2005 split-share structure reform in China

To overcome the aforementioned endogeneity concerns, we used firm-level adoption of split-share reform as the first quasi-natural experiment. The split-share structure reform increased the supply of tradable shares and, hence, liquidity (e.g., Liao et al., 2014; Campello et al., 2014), providing us with an ideal study setting. The institutional details of the reform and how it affected stock liquidity are discussed in the Appendix. We performed three types of analyses using this quasi-natural experiment. First, we performed a difference-in-difference (DiD) analysis exploiting the split-share reform to examine how corporate investment decisions are affected by an increase in stock liquidity using a sample of propensity score-matched firms, in which treated firms experience large liquidity shocks, while control firms face smaller changes in liquidity with respect to the reform. Second, we conducted a change regression analysis to examine investment efficiency in the post-split-share reform period using changes in key explanatory and control variables from one year before the adoption of the split-share reform to one year after. Finally, we investigated announcement reactions to the reform by computing the cumulative abnormal return during the resumption of trading by firms that enter the split-share structure reform process.[8]

4. Empirical results

4.1. Baseline linear regression specifications

We used two baseline specifications to examine the relationship between stock liquidity and investment efficiency. First, we regressed investment on stock liquidity, *ex ante* investment propensity, their interaction terms, and the control variables as follows:

[7] To mitigate the effect of outliers on our findings, we winsorized all continuous variables at the 1st and 99th percentiles.

[8] The announcement of the adoption of the split-share structure reform adoption coincides with a trading suspension when the negotiation takes place with the shareholders to seek their agreement on the compensation plan to convert the non-tradable shares to tradable shares. Once the plan is finalized, it is put to a shareholder vote and then implemented if successful. If not, negotiations with shareholders resume.

Table 2
Summary statistics.

	Full sample ($N = 11{,}305$)					Firms with high stock liquidity ($N = 6208$)		Firms with low stock liquidity ($N = 5097$)		Test of difference: High liquidity– Low liquidity	
Variables	Q1	Mean	Median	Q3	S.D.	Mean	Median	Mean	Median	Mean	Median
INVEFF	−0.065	−0.057	−0.035	−0.015	0.076	−0.054	−0.033	−0.061	−0.038	0.007***	0.005***
INV	−0.011	0.031	0.004	0.044	0.098	0.035	0.008	0.025	0.000	0.010***	0.008***
LIQ	−0.123	−0.124	−0.056	−0.028	0.192	−0.031	0.030	−0.237	0.138	0.206***	−0.108***
LOGASSET	21.008	21.877	21.758	22.603	1.252	22.369	22.210	21.277	21.222	1.092***	0.988***
Q	0.761	1.976	1.374	2.453	1.859	2.152	1.591	1.760	1.159	0.392***	0.432***
SD_CFO	0.031	0.060	0.049	0.076	0.043	0.056	0.046	0.064	0.051	−0.008***	−0.005***
SD_SALE	0.060	0.140	0.102	0.171	0.129	0.135	0.099	0.146	0.107	−0.011***	−0.008***
SD_INV	0.025	0.073	0.053	0.099	0.065	0.073	0.051	0.074	0.056	−0.001	−0.005***
Z	1.748	5.335	3.041	5.589	7.573	6.035	3.485	4.482	2.565	1.553***	0.920***
TANG	0.125	0.263	0.231	0.377	0.179	0.253	0.216	0.274	0.249	−0.021***	−0.033***
KSTR	0.059	0.192	0.174	0.294	0.154	0.178	0.158	0.210	0.196	−0.032***	−0.038***
IND_KSTR	0.120	0.182	0.180	0.220	0.065	0.168	0.165	0.199	0.194	−0.031***	−0.029***
CFO_SALE	0.008	0.074	0.071	0.159	0.240	0.084	0.077	0.062	0.064	0.022***	0.013***
SLACK	0.265	2.494	0.638	1.604	7.137	2.691	0.721	2.254	0.563	0.437***	0.158***
DIV	0.000	0.621	1.000	1.000	0.485	0.724	1.000	0.495	0.000	0.229***	1.000
AGE	12.000	15.475	15.000	19.000	5.177	16.252	16.000	14.527	14.000	1.725***	2.000***
OPERATINGCYCLE	4.354	5.039	5.022	5.667	1.104	5.012	5.001	5.073	5.052	−0.061***	−0.051**
LOSS	0.000	0.119	0.000	0.000	0.323	0.080	0.000	0.166	0.000	−0.086***	0.000
CASH	0.081	0.162	0.133	0.214	0.115	0.170	0.140	0.153	0.125	0.017***	0.015***
ANALYSTS	0.000	6.088	2.000	9.000	8.367	8.857	6.000	2.715	1.000	6.142***	5.000***
SOE	0.000	0.610	1.000	1.000	0.488	0.611	1.000	0.609	1.000	0.002	0.000
CEO_DUAL	0.000	0.191	0.000	0.000	0.393	0.200	0.000	0.180	0.000	0.020***	0.000

This table reports summary statistics for variables constructed using a sample of Chinese public firms. The sample consists of non-financial firms with non-missing data in the CSMAR and Wind databases between the years 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. The sample is divided into two groups according to stock liquidity measured as −1 times the natural logarithm of $(1 + Amihud)$. In the last two columns consisting of the test of the difference in means and medians between the two subgroups, superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

$$INV_{i,t+1} = a + bLIQ_{i,t} + cUNDER\_PROP_{i,t} + dLIQ_{i,t} \times UNDER\_PROP_{i,t} + e'\boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}, \quad (3)$$

where $UNDER\_PROP_{i,t}$ is a proxy for firm i's *ex ante* propensity to under-invest in year t. This propensity is computed as a ranked variable based on the average ranks of the cash ratio and leverage deciles, in which the cash ratio is multiplied by minus one to allow the two decile ranks to increase with the likelihood of under-investment (Biddle et al., 2009).[9]

We also performed OLS regressions in which the dependent variable is the investment efficiency measure, computed as the absolute value of the deviation of the actual investment rate from the expected investment rate multiplied by minus one. We conducted regression analyses on our full sample and subsamples of under-investing and over-investing firms. Firm years with positive (negative) residuals in the regressions in Eq. (2) are grouped into a subsample of over-investing (under-investing) firms. The regression model is as follows:

$$INVEFF_{i,t+1} = a + bLIQ_{i,t} + c'\boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}. \quad (4)$$

Following Biddle et al. (2009), we controlled for the volatility of cash flows, sales, and investments to mitigate the effects of accruals, the cost of capital, and investment mean reversion, respectively (Liu and Wysocki, 2017; Biddle et al., 2009; Polk and Sapienza, 2008). Furthermore, to account for the business cycle's effect on investment behavior, we include firm age, operating cycle length, and an indicator of loss (Dechow, 1994; Dechow et al., 1998; Dechow and Dichev, 2002). In addition, we included firm size, growth opportunities, leverage at the firm and industry levels, tangibility, financial slack, cash, and bankruptcy risk because these firm characteristics can have a pronounced effect on firm investment.

Moreover, we controlled for governance variables, including the number of analysts tracking the firm, and indicators of state ownership and of chairperson–CEO duality. In estimating both Eqs. (3) and (4), we used a pooled OLS specification with robust standard errors clustered at the firm level (Petersen, 2009). We also included year and industry dummies to control for the unobserved time- and industry-specific heterogeneity in investment behavior. We defined the industries using 32 CSRC industry classification codes.

Table 3 reports the results of OLS regressions of stock liquidity on investment efficiency. Columns (1)–(3) in Panel A examine the conditional relationship between investment and stock liquidity, i.e., how stock liquidity affects a firm's investments conditional on the firm being more prone to under-invest (Biddle et al., 2009). To proxy for the under-investment propensity, we used a firm-, economy-, and industry-year-level measures, in Columns (1)–(3), respectively. In all three columns, the interaction between stock liquidity and the propensity to under-invest is significant at the 1% level, indicating that conditional on being more prone to under-invest (over-invest), stock liquidity is positively (negatively) associated with investment rate. Regarding economic significance, the results in Columns (1)–(3) of Panel A suggests that a combined one-standard-deviation increase in stock liquidity (0.192) and under-investment propensity increases investment by between 46 and 55 basis points, over and above the individual effect of these variables on investment. Considering the mean value of investment in our sample is 3.1%, this effect is economically meaningful—at around 15–17% of the mean value of investment.

To examine whether under- or over-investing firms drive the findings in Panel A, we examined the effect of stock liquidity on our investment efficiency measure (*INVEFF*), computed as the absolute value of the deviation multiplied by minus one for our full sample and subsamples of under- and over-investing firms; the results are presented in the first three columns of Panel B of Table 3. Consistent with our hypothesis, we found that stock liquidity is significantly and positively associated with the investment efficiency measure only for the subsample of under-investing firms, as shown by the significantly positive coefficient in Column (2) of Panel B. In terms of economic significance, a one-standard-deviation increase in stock liquidity (0.192) reduces investment inefficiency for under-investing firms by 8.3% of the under-investing subsample mean (0.044).[10] Column (3) of Panel B shows that stock liquidity has no significant effect on investment efficiency when firms over-invest.

Our approach to computing the *INVEFF* measure based on residuals from industry-year regressions does not control for the possibility that the variance in investment across industry years differs. To mitigate this concern, we divided the absolute values of the residuals from an industry-year regression by the standard deviation of the residuals and multiplied them by minus one to define an

[9] To overcome the concern that this measure can be endogenously correlated with stock liquidity due to omitted variables, following Biddle et al. (2009), we used alternative plausibly exogenous measures to capture a firm's under-investment propensity. $UNDER\_AGGPROP_{i,t}$ ($UNDER\_INDPROP_{i,t}$) is a ranked variable at the aggregate-economy (industry-year) level computed based on the unexplained aggregate investment rate (industry-year investment rate), i.e., residuals obtained from regressing investment rate on lagged sales growth for all firms (investment rate on lagged sales growth in each industry-year). Both the residuals are multiplied by minus one to allow these measures to increase with the likelihood of under-investment.

[10] The unreported sample mean investment inefficiency for the under-investing subsample is 0.044. Note that to facilitate interpretation we get a measure of investment efficiency by multiply a measure of investment inefficiency by −1. Thus, the sample mean investment efficiency for the under-investing subsample is −0.044.

Table 3
Effect of stock liquidity on investment efficiency—Baseline results.

Panel A: Conditional effect of stock liquidity on investment

	Dep. var.: *INV*		
	Under-investment propensity measured using		
	Firm-level cash & leverage	Full sample residual	Industry-year residual
Variables	(1)	(2)	(3)
LIQ	0.017*	−0.055***	−0.052***
	(0.010)	(0.018)	(0.019)
UNDER_PROP	0.002		
	(0.002)		
UNDER_AGGPROP		−0.025***	
		(0.000)	
UNDER_INDPROP			−0.025***
			(0.000)
LIQ × *UNDER_PROP*	0.011***		
	(0.003)		
LIQ × *UNDER_AGGPROP*		0.008***	
		(0.002)	
LIQ × *UNDER_INDPROP*			0.007***
			(0.002)
Control variables			
LOGASSET	−0.001	−0.002	−0.001
	(0.001)	(0.001)	(0.001)
Q	0.004***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)
SD_CFO	0.012	0.049***	0.037**
	(0.027)	(0.018)	(0.018)
SD_SALE	−0.010	−0.016***	−0.013**
	(0.009)	(0.006)	(0.006)
SD_INV	0.079***	0.057***	0.056***
	(0.021)	(0.015)	(0.015)
Z	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)
TANG	−0.096***	−0.023***	−0.029***
	(0.011)	(0.007)	(0.007)
KSTR	0.046**	0.018***	0.017**
	(0.019)	(0.007)	(0.007)
IND_KSTR	−0.037	−0.006	0.018
	(0.046)	(0.031)	(0.031)
CFO_SALE	0.007	0.007*	0.005
	(0.005)	(0.004)	(0.004)
SLACK	0.000*	0.000**	0.000*
	(0.000)	(0.000)	(0.000)
DIV	−0.000	−0.007***	−0.006***
	(0.002)	(0.002)	(0.002)
AGE	−0.001***	0.000	0.000
	(0.000)	(0.000)	(0.000)
OPERATINGCYCLE	−0.010***	−0.008***	−0.007***
	(0.002)	(0.001)	(0.001)
LOSS	−0.021***	−0.006**	−0.005*
	(0.004)	(0.003)	(0.003)
CASH	−0.026	−0.024***	−0.026***
	(0.021)	(0.007)	(0.007)
ANALYSTS	0.001***	−0.000***	−0.000**
	(0.000)	(0.000)	(0.000)
SOE	0.001	0.003*	0.003*
	(0.002)	(0.002)	(0.002)
CEO_DUAL	0.005*	0.003	0.002
	(0.002)	(0.002)	(0.002)
CONSTANT	0.131***	0.233***	0.192***
	(0.036)	(0.026)	(0.026)
Industry FE	Y	Y	Y
Year FE	Y	Y	Y
Observations	11,161	11,161	11,161
R-squared	0.067	0.557	0.562

(*continued on next page*)

Table 3 (*continued*)

Panel B: Effect of stock liquidity on investment efficiency

	Dep. var.: *INVEFF*			Dep. var.: *INVEFF_STD*		
	Full sample	Under-investing subsample	Over-investing subsample	Full sample	Under-investing subsample	Over-investing subsample
Variables	(1)	(2)	(3)	(4)	(5)	(6)
LIQ	0.012	0.019***	0.005	0.159	0.251***	0.069
	(0.007)	(0.005)	(0.018)	(0.098)	(0.063)	(0.245)
Control variables						
LOGASSET	−0.003***	−0.001	−0.008***	0.043***	0.012	0.113***
	(0.001)	(0.001)	(0.003)	(0.015)	(0.008)	(0.036)
Q	0.004***	0.001***	0.010***	−0.056***	−0.017***	−0.132***
	(0.001)	(0.000)	(0.002)	(0.012)	(0.007)	(0.032)
SD_CFO	0.009	0.004	0.001	−0.123	−0.059	−0.007
	(0.020)	(0.010)	(0.051)	(0.267)	(0.139)	(0.688)
SD_SALE	−0.006	−0.002	−0.023	0.080	0.028	0.310
	(0.006)	(0.004)	(0.015)	(0.082)	(0.049)	(0.201)
SD_INV	0.070***	0.012	0.139***	−0.938***	−0.158	−1.873***
	(0.016)	(0.009)	(0.039)	(0.213)	(0.120)	(0.531)
Z	−0.000*	−0.000	−0.001	0.004*	0.002	0.008
	(0.000)	(0.000)	(0.001)	(0.002)	(0.001)	(0.007)
TANG	0.009	0.056***	−0.068***	−0.116	−0.750***	0.917***
	(0.008)	(0.004)	(0.020)	(0.104)	(0.058)	(0.271)
KSTR	0.030***	0.000	0.061***	−0.399***	−0.002	−0.823***
	(0.007)	(0.004)	(0.019)	(0.097)	(0.054)	(0.251)
IND_KSTR	−0.040	−0.034*	−0.026	0.538	0.452*	0.347
	(0.031)	(0.020)	(0.074)	(0.416)	(0.273)	(0.990)
CFO_SALE	0.004	−0.001	0.013	−0.057	0.017	−0.169
	(0.004)	(0.002)	(0.008)	(0.049)	(0.027)	(0.114)
SLACK	0.000	−0.000	0.000	−0.002	0.001	−0.004
	(0.000)	(0.000)	(0.000)	(0.002)	(0.001)	(0.004)
DIV	−0.008***	−0.004***	−0.017***	0.113***	0.058***	0.231***
	(0.002)	(0.001)	(0.004)	(0.024)	(0.014)	(0.061)
AGE	−0.000	0.000***	0.000	0.000	−0.004***	−0.002
	(0.000)	(0.000)	(0.000)	(0.002)	(0.001)	(0.006)
OPERATINGCYCLE	−0.006***	−0.000	−0.013***	0.082***	0.004	0.169***
	(0.001)	(0.001)	(0.003)	(0.015)	(0.008)	(0.040)
LOSS	0.008***	0.012***	0.008	−0.103***	−0.165***	−0.112
	(0.003)	(0.002)	(0.009)	(0.039)	(0.025)	(0.121)
CASH	−0.018**	0.006	−0.060***	0.239**	−0.087	0.813***
	(0.008)	(0.004)	(0.022)	(0.108)	(0.055)	(0.297)
ANALYSTS	−0.000	−0.000***	−0.000	0.001	0.004***	0.005
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.003)
SOE	0.002	−0.002*	0.011**	−0.022	0.024*	−0.145**
	(0.002)	(0.001)	(0.004)	(0.022)	(0.013)	(0.060)
CEO_DUAL	0.003*	−0.000	0.008*	−0.043*	0.004	−0.107*
	(0.002)	(0.001)	(0.005)	(0.024)	(0.014)	(0.063)
CONSTANT	0.131***	0.040**	0.269***	−1.765***	−0.541**	−3.628***
	(0.028)	(0.016)	(0.066)	(0.376)	(0.213)	(0.891)
Industry FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	11,140	7388	3752	11,140	7388	3752
R-squared	0.112	0.252	0.144	0.112	0.252	0.144

This table presents estimates of the pooled OLS regressions testing the effect of stock liquidity on investment efficiency. The sample consists of non-financial firms with non-missing data in the CSMAR and Wind databases between the years 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. Panel A report results of the mdel: $INV_{i,t+1} = a + bLIQ_{i,t} + cUNDER\_PROP_{i,t} + dLIQ_{i,t} \times UNDER\_PROP_{i,t} + c' \boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}$; Panel B report results of the model: $INVEFF_{i,t+1} = a + bLIQ_{i,t} + c' \boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}$. *INVEFF_STD* is computed by dividing *INVEFF* with the cross-sectional sample standard deviation. *UNDER_PROP* is computed as the average of a measure based on the ranks of cash ratio and leverage deciles, in which cash is multiplied by minus one to ensure both variables to increase with the likelihood of under-investment. *UNDER_AGGPROP* is a measure of under-investment propensity at the aggregate-economy level computed as the negative of the residual from the full-sample regression of the firm-year investment rate on firm-year lagged sales growth. *UNDER_INDPROP* is a measure of under-investment propensity at the industry-year level computed as the negative of the residual from the regression of the firm-year investment rate on the firm-year lagged sales growth executed for each industry-year. To obtain both *UNDER_AGGPROP* and *UNDER_INDPROP*, the residuals are multiplied by minus one to ensure the measure to increase with the likelihood of under-investment. In Panel B, columns (2) and (5) (columns (3) and (6)), the model is estimated using the subsample of under-investing firms (over-investing firms), which are identified as firms that have a negative (positive) deviation from expected rate of investment in a given year. Robust standard errors clustered by firm are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

alternative investment efficiency measure, denoted by *INVEFF_STD*. The results in Columns (4)–(6) of Panel B are similar to those in the first three columns, suggesting that the clustering of residuals across industry years does not drive our findings. Overall, the results in Table 3 are consistent with our hypothesis that, while stock liquidity improves the investment efficiency of under-investing firms, it does not have a remarkable effect on over-investing firms.[11]

Brennan et al. (2013) decomposed the Amihud illiquidity measure based on the sign of daily stock returns and found that only stock liquidity linked to negative stock return days is priced in the cross-section of stock returns. They argued that illiquidity traps (i.e., fear of ending up with a stock that cannot be sold during a crisis) and a leverage effect (i.e., leveraged investors might need to sell when prices fall) might be contributing factors that drive the relationship between stock liquidity and stock returns when prices fall. Thus, we followed their method and condition—the Amihud illiquidity measure on up-return versus down-return days—and examined their relationships with investment efficiency.

Table 4 reports the results of the estimation of Eqs. (3) and (4) with these two measures of stock liquidity. In Columns (1) and (2), the key variable of interest is the interaction between *UP_LIQ* (*DOWN_LIQ*) and under-investment propensity (*UNDER_PROP*). We found that the estimated coefficients on both interaction terms are positive and significant when each is included separately, suggesting that stock liquidity on both days with positive and negative returns improves investment efficiency. However, in Column (3), when we included both measures of liquidity simultaneously, we only found a significant coefficient on *DOWN_LIQ* × *UNDER_PROP*, suggesting that firms with greater stock liquidity on negative return days invest more efficiently than those with greater stock liquidity on positive return days. In Columns (4)–(6), we used *INVEFF* as the dependent variable and these two measures of stock liquidity as key explanatory variables over the full sample and subsamples of under- and over-investing firms. We found that only the coefficient on *DOWN_LIQ* was negative (positive) and significant in Columns (5) and (6), suggesting that the stock liquidity during negative return days only matters for investment efficiency. In equilibrium, if we assume that the liquidity's return premium proxies for the cost of capital firms face, these results in Table 4 indicate that having higher stock liquidity on negative return days may lower the cost of capital and facilitate more investment for under-investing firms.

To further examine the effect of stock liquidity on investment efficiency, we adopted an investment–Q sensitivity analysis, following Chen et al. (2007). Specifically, we regressed the measure of investment on Q (a measure of investment opportunities), firm cash flow, firm size, stock liquidity, and the interaction between stock liquidity and Q as follows:

$$INV_{i,t+1}\left(\text{or } CAPX_{i,t+1}\right) = a + bLIQ_{i,t} + cQ_{i,t} + dLIQ_{i,t} \times Q_{i,t} + eCF_{i,t+1} + fINV\_ASSET_{i,t} + YR_{t+1} + FIRM_i + \varepsilon_{i,t+1}, \quad (5)$$

where $INV\_ASSET_{i,t}$ is the inverse of the natural logarithm of the firm's total assets, and $CF_{i,t+1}$ is the cash flow from operating activities scaled by total assets. We also used $CAPX_{i,t+1}$ as an alternative dependent variable, which allowed us to examine the robustness of our findings. $CAPX_{i,t+1}$ is defined as the ratio of capital expenditures to lagged total assets. The positive coefficient of *Q* suggests that investments are sensitive to opportunities. Similarly, a positive coefficient of the interaction between a conditioning variable and *Q* suggests that investment-Q sensitivity is higher for firms with a greater conditioning variable value.[12] In the context of Eq. (5), the significantly positive coefficient *d* implies that investment-Q sensitivity is higher for firms with higher stock liquidity.

Table 5 reports the results of the estimation of Eq. (5) using our sample. In Panel A, Columns (1)–(2), we examine whether stock liquidity influences the investment-Q sensitivity in the full sample of firms. Columns (3)–(4) (Columns (5)–(6)) of Panel A perform the same estimation using a subsample of firms with greater likelihood of under-investment (over-investment) as used in Column (2) and (3) of Panel B in Table 3. The key variable of interest is the interaction between stock liquidity and Q. In Column (2), using the level of capital expenditures as a measure of investment, we found a positive and significant coefficient on $LIQ_{i,t} \times Q_{i,t}$ suggesting that firms with greater stock liquidity exhibit a greater sensitivity of investment to Q. However, in Column (1), using our standard measure of investment, the coefficient on the interaction term is positive but insignificant. Splitting our sample into firms with higher and lower under-investment propensities, we found that the results of the positive effects in Columns (1) and (2) in Panel A are entirely driven by firms with greater likelihood of under-investment (i.e., coefficients on the interaction terms are positive and significant in both Columns (3) and (4) in Panel B). These results are consistent with those in Table 3 and suggest that under-investing firms benefit more from higher stock liquidity and seem to show a greater sensitivity of investment to growth opportunities, i.e., they invest more efficiently.

Chen et al. (2007) found that price informativeness is positively correlated with investment-Q sensitivity. Measures of price informativeness such as price non-synchronicity capture private information in the stock price and allow managers to learn from stock prices, which the authors interpreted as evidence of the "feedback" effect. However, most empirical studies on "feedback" effects rely on data from developed countries, and it is unclear whether managers in developing countries pay attention to stock prices. Thus, following Chen et al. (2007), we examined whether stock liquidity influences investment-Q sensitivity by controlling price informativeness. To that extent, we re-estimated the regressions in Panel A of Table 5 using subsamples of low and high stock price non-

[11] To overcome the concern that the classification of firms into under- and over-investing groups is volatile around the mean changes in investment opportunities in the economy across time, in untabulated tests, we re-estimate the regressions in Columns (1)–(3) of Panel B in Table 3 with additional controls for the deviations in investments from expected investment rates in the previous three years. We found that the coefficient on stock liquidity is still negative and significant in the under-investing subsample. We also found that the coefficient on the past deviations in investments over the previous three years was positive and significant in the previous three years, suggesting that under-investment behavior of firms relative to peers is quite persistent over the years.

[12] Foucault and Frésard (2012) considered cross-listing as the conditioning variable in similar setting.

Table 4
Decomposing liquidity into up- and down-return days.

	Dep. var.: *INV*			Dep. var.: *INVEFF*		
	Under-investment propensity measured using firm-level cash & leverage			Full sample	Under-investing subsample	Over-investing subsample
Variables	(1)	(2)	(3)	(4)	(5)	(6)
UP_LIQ	31.747		−25.110	−0.423	−1.460	18.822
	(34.264)		(67.751)	(0.966)	(1.017)	(15.258)
DOWN_LIQ		66.292***	70.039	−20.516	57.499**	−155.957**
		(24.521)	(46.654)	(26.267)	(22.998)	(75.215)
UNDER_PROP	0.001	0.001	0.001			
	(0.002)	(0.002)	(0.002)			
UP_LIQ × *UNDER_PROP*	39.288**		9.397			
	(19.005)		(19.054)			
DOWN_LIQ × *UNDER_PROP*		19.140**	12.331*			
		(9.100)	(7.132)			
Controls in Table 3	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	11,160	11,161	11,160	11,139	7387	3752
R-squared	0.065	0.066	0.045	0.111	0.251	0.146

This table presents estimates of the pooled OLS regressions of investment efficiency. The sample consists of non-financial firms with non-missing data in the CSMAR and Wind databases between the years 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. Columns (1)–(3) report results of the model $INV_{i,t+1} = a + bLIQ_{i,t} + cUNDER\_PROP_{i,t} + dLIQ_{i,t} \times UNDER\_PROP_{i,t} + e' \boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}$. Columns (4)–(6) report results of the model $INVEFF_{i,t+1} = a + bLIQ_{i,t} + c' \boldsymbol{Controls}_{i,t} + YR_{t+1} + IND_i + \varepsilon_{i,t+1}$. *LIQ* is computed either as *UP_LIQ* or *DOWN_LIQ*, measured as the $-log(1 + Amihud)$ but averaged only over days with positive and negative returns, respectively. *UNDER_PROP* is computed as the average of a measure based on the ranks of cash and leverage deciles, in which cash is multiplied by minus one to allow both variables to increase with the likelihood of under-investment. In column (5) (column (6)), the model is estimated using the subsample of under-investing firms (over-investing firms), which are identified as firms that have a negative (positive) deviation from expected rate of investment. Robust standard errors clustered by firms are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

synchronicity ($1 - R^2$), measured as one minus the R^2 from the regressions of daily returns on Shanghai Composite Index returns and CSRC industry value-weighted returns.[13] Panel B of Table 5 reports the estimation results for Eq. (5) using these subsamples based on price informativeness (i.e., price non-synchronicity). For brevity, we do not report over-investing subsample results. We found that the interaction term $LIQ_{i,t} \times Q_{i,t}$ is positive and significant only among the more informative stock price subsample (i.e., the high ($1 - R^2$) subsample), especially among under-investing firms (i.e., Columns (6)–(8)). These findings confirm that managers make efficient investment decisions when stock prices are more informative and stocks are liquid, thus supporting the feedback effect on Chinese stocks.

4.2. Addressing endogeneity concerns

4.2.1. DiD approach

Following closely the analyses in Fang et al. (2014), we performed a set of DiD analyses surrounding the split-share structure reform as a quasi-natural experiment, which can confirm the causal inference on the effect of stock liquidity on investment efficiency. We first sorted firms into terciles based on the increase in three-year average stock liquidity surrounding the split-share reform (i.e., three-year average liquidity after the reform and less three-year average liquidity before the reform).[14] Firms in the top tercile constitute the

[13] The Shanghai composite index is used as a proxy for the market return as it has the widest coverage and historical availability.

[14] Even after the implementation of the split-share structure reform, the non-tradable shares do not become readily eligible for trading. After the first 12 and 24 months, each investor can trade up to 5% and 10% of total shares outstanding, respectively. After 36 months, all the non-tradable shares become eligible for trading. Thus, in our construction of treatment and control groups, we relied on a relatively longer post-split-share structure reform period of three years, to account for the lock-up periods.

treatment group, whereas the remaining firms are included in the control group, implying that the treated firms have the largest increases in stock liquidity with respect to reform. Next, we matched each treatment firm with a control firm and computed the propensity score using the nearest neighborhood algorithm without replacement.[15] Using the propensity score-matched sample for the reform adoption year, we compared the changes in firm investment efficiency surrounding the reform between the treated and control firms.

The definitions of the additional variables used in the DiD analysis are presented in Table 6 Panel A. To check the validity of the split-share structure reform as an exogenous shock to liquidity in Column (1) of Panel B, we regressed stock liquidity on the fraction of non-tradable shares (NTS) in a firm. The coefficient of *NTS_FRACTION* was negative and significant at the 1% level, suggesting that firms with a large proportion of non-tradable shares have significantly lower liquidity. In Column (2) of Panel B, we regressed *NTS_FRACTION* on an indicator of split-share structure reform and found a negative association, suggesting that firms that undergo split-share structure reform witness a decrease in the proportion of non-tradable shares. In Column (3), we regressed stock liquidity on split-share structure reform and found a positive association, indicating that the reform increases stock liquidity. In summary, the results in Panel B of Table 6 suggest that non-tradable shares are a significant determinant of stock liquidity, and that the conversion of non-tradable to tradable shares through the split-share structure reform improves stock liquidity.

In Panels C to E, we obtained the propensity score-matched sample and performed various diagnostic tests to alleviate any concern about the endogeneity of firm-level adoption of the split-share structure reform and subsequently increase confidence in the validity of our DiD estimator. Specifically, Panel C presents the estimates of a probit model in which the dependent variable is an indicator that takes the value of one for firms in the treatment group and zero otherwise. The pseudo R-squared in Column (1) was as high as 52.0%, suggesting that our matching variables captured significant variations in the treatment assignment. In Column (2) of Panel C, we estimated the probit model using the matched sample and found that none of the matching variables were statistically significant in explaining the likelihood of treatment, reinforcing the validity of the DiD estimate.[16] The pseudo-R-squared also drops drastically to 6.4%, suggesting no significant difference between the treated and control firms in terms of observable variables; therefore, treatment assignment is plausibly random within this matched group of firms. Additionally, the distribution of the propensity scores between the treated and control firms reported in Panel D shows a trivial difference between the two groups of firms. In Panel E, we compared the means of various observable firm characteristics between the treated and control firms and reported the corresponding *t*-statistics. All the differences were insignificant at conventional levels.

Panel F of Table 6 reports the results of univariate DiD analyses using our propensity score-matched sample. First, we found that within our full sample of firms, neither *INV* and *INVEFF* appear to be affected by the split-share structure reform. However, as hypothesized, when we divided the sample into under- and over-investing firms, we found sharp differences.[17] The subsample analyses suggest that increased stock liquidity improves the investment efficiency of under-investing firms but does not significantly influence the investment efficiency of over-investing firms. These findings indicate that stock liquidity has a causal effect on the mitigation of unde-rinvestment. The average treatment effect of stock liquidity on under-investing firms' *INV* (*INVEFF*) increased by 3.4 percentage points (2.5 percentage points). Given that the average *INV* (*INVEFF*) prior to the split-share structure reform in the subsample of under-investing firms is 1.7 percentage points (−6.9 percentage points), this effect is economically large.

Panel G of Table 6 reports the results of multivariate DiD tests using the propensity score-matched sample. To capture the time-varying effects of the split-share structure reform, we defined new indicator variables based on the time relative to reform adoption, the year of which differs across firms. Specifically, we defined $BEFORE^{-1}$ as a new variable that takes the value of one for a firm-year observation one year prior to the split-share reform and zero otherwise. Next, we defined *CURRENT* as an indicator variable, that equals one for a firm-year observation in the year of the split-share reform and zero otherwise. Finally, we defined $AFTER^{1}$ ($AFTER^{23}$), as an indicator variable, which takes the value of one for a firm-year observation one year (two to three years) after the split-share reform, and zero otherwise. Using *INV* and *INVEFF* measured in the seven-year period surrounding reform adoption as dependent variables, we performed multivariate DiD analyses. We estimated the regressions using the full sample and subsamples of under- and over-investing firms.

In Column (1), we found that *INV* increases significantly following the split-share structure reform in the full sample. In Columns (2) and (3), we found that this positive and significant effect is evident in the first year, that is, $TREAT \times AFTER^{1}$ (in the second and third years, that is, $TREAT \times AFTER^{23}$) in the under-investing (over-investing) subsample. These results suggest that the reforms improve (worsen) the investment efficiency of under-investing (over-investing) firms. In Columns (4)–(6), examining *INVEFF*, we found similar evidence. *INVEFF* is higher (lower) for under-investing (over-investing) firms in the second and third years following the

[15] Since the validity of the DiD estimate critically depends on the parallel-trends assumption, we executed several diagnostic tests to verify that we do not violate this assumption, following Fang et al. (2014). First, we examined whether any of the independent variables were statistically significant in the probit model restricted to the matched sample. Second, we examined whether propensity scores of the treatment firms and those of the matched control firms were sufficiently close. Third, we examined whether any of the pre-reform characteristics were similar between the treatment and control groups. Our analyses showed that the parallel trends assumption was satisfied. Details of this analysis are available from the authors upon request.

[16] Using these predicted probabilities from the probit model, we performed a nearest-neighbor propensity-score matching without replacement. A firm in the top tercile of the stock liquidity change was matched with a control firm with the closest propensity score. This procedure provided us with 132 firms constituting the treated and control firm pairs.

[17] In dividing the sample, consistent with our baseline specification in Table 3, we split the sample using an *ex ante* measure of under-investment propensity (*ex post* measure of under-investment) when examining the difference in *INV* (*INVEFF*).

Table 5
Effect of stock liquidity on investment-Q sensitivity.

Panel A: Investment-Q sensitivity by stock liquidity

	Full sample		Under-investing subsample		Over-investing subsample	
	Dep. var.: *INV*	Dep. var.: *CAPX*	Dep. var.: *INV*	Dep. var.: *CAPX*	Dep. var.: *INV*	Dep. var.: *CAPX*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
LIQ	−0.022	0.003	−0.227	−0.035	−0.083	0.012
	(0.077)	(0.016)	(0.178)	(0.038)	(0.076)	(0.010)
Q	0.048*	0.019***	0.191*	0.051**	0.005	0.003***
	(0.026)	(0.006)	(0.101)	(0.021)	(0.015)	(0.001)
LIQ × *Q*	0.055	0.018**	0.222*	0.049**	0.005	0.001
	(0.043)	(0.008)	(0.119)	(0.023)	(0.026)	(0.003)
CF	1.857***	0.539***	1.838***	0.471***	1.608***	0.239***
	(0.362)	(0.080)	(0.456)	(0.095)	(0.340)	(0.024)
INV_ASSET	0.126*	0.017	0.227	0.029	0.027	−0.001
	(0.077)	(0.014)	(0.177)	(0.030)	(0.036)	(0.003)
CONSTANT	−0.225**	0.011	−0.378*	−0.001	−0.190***	0.042***
	(0.094)	(0.019)	(0.229)	(0.044)	(0.064)	(0.007)
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	8786	8763	4200	4186	4586	4577
R-squared	0.190	0.284	0.255	0.320	0.385	0.595

Panel B: Investment-Q sensitivity by stock liquidity and informed trading

	Dep. var.: *INV*	Dep. var.: *CAPX*	Dep. var.: *INV*	Dep. var.: *CAPX*	Dep. var.: *INV*	Dep. var.: *CAPX*	Dep. var.: *INV*	Dep. var.: *CAPX*
	Low $(1–R^2)$ subsample				High $(1–R^2)$ subsample			
	Full sample		Under-investing subsample		Full sample		Under-investing subsample	
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LIQ	0.031	0.018	0.097***	0.039	0.017	−0.030	−0.006	−0.055
	(0.020)	(0.019)	(0.024)	(0.036)	(0.025)	(0.021)	(0.028)	(0.032)
Q	0.001	0.009**	0.008*	0.019**	0.010***	0.008*	0.020***	0.025***
	(0.003)	(0.004)	(0.005)	(0.007)	(0.003)	(0.004)	(0.006)	(0.007)
LIQ × *Q*	0.011	0.022	−0.029	0.016	−0.003	0.024**	0.025**	0.038*
	(0.010)	(0.017)	(0.029)	(0.023)	(0.009)	(0.011)	(0.011)	(0.020)
CF	−0.002	0.002	−0.019	−0.002	−0.006	0.009	−0.011	−0.008
	(0.007)	(0.010)	(0.012)	(0.012)	(0.007)	(0.014)	(0.009)	(0.037)
INV_ASSET	0.302***	0.336***	0.327***	0.368***	0.091***	0.488***	0.075***	0.530***
	(0.045)	(0.077)	(0.046)	(0.063)	(0.022)	(0.076)	(0.020)	(0.050)
CONSTANT	0.012**	0.036***	0.023**	0.038***	0.003	0.007	0.004	0.003
	(0.005)	(0.007)	(0.009)	(0.012)	(0.007)	(0.012)	(0.010)	(0.031)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	4897	4897	2307	2307	3449	3449	1457	1457
R-squared	0.290	0.438	0.338	0.460	0.365	0.643	0.389	0.795

This table presents estimates of the pooled OLS regressions testing the effect of stock liquidity on investment-Q sensitivity, in the spirit of Chen et al. (2007). In both panels, the sample consists of non-financial firms with non-missing data in the CSMAR and Wind databases between 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. In Panel A, Columns (1), (3), and (5) (Columns (2), (4), and (8)) report results of the model $INV_{i,t+1}\left(\text{or } CAPX_{i,t+1}\right) = a + bLIQ_{i,t} + cQ_{i,t} + dLIQ_{i,t} \times Q_{i,t} + eCF_{i,t+1} + fINV\_ASSET_{i,t} + YR_{t+1} + FIRM_i + \varepsilon_{i,t+1}$. All the variables are measured following Chen et al. (2007). *INV* is computed as the change in fixed assets scaled by lagged total assets. *CAPX* is computed as capital expenditure scaled by lagged total assets. *INV_ASSET* is the inverse of the logarithm of assets. In Panel A, Columns (1) and (2), the models are estimated using the full sample, while in Columns (3)–(4) (Columns (5)–(6)), the models are estimated using the subsample of under-investing firms (over-investing firms), which are identified as firms that have a negative (positive) deviation from expected rate of investment. Panel B presents the results in Columns (1)–(4) of Panel A separately for firms with lower and higher than sample median $1 - R^2$, where R^2 is computed by regressing the daily return on market (i.e., Shanghai Composite Index) and industry index over the year. Robust standard errors clustered by firms are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6
Difference-in-differences (DiD) analysis around the split-share structure reform.

Panel A: Definition of new variables

Variables	Definitions
TREAT	An indicator variable that takes the value of one for treated firms and zero for control firms
BEFORE^{-1}	An indicator variable that takes the value of one for a firm-year observation one year before the split-share reform and zero otherwise.
CURRENT	An indicator variable that takes the value of one for a firm-year observation in the year of split-share reform and zero otherwise.
AFTER^{1}	An indicator variable that takes the value of one for a firm-year observation one year after the split-share reform and zero otherwise.
AFTER^{23}	An indicator variable that takes the value of one for a firm-year observation 2 or 3 years after the split-share reform and zero otherwise.
BEFORE_INVEFF	Mean *INVEFF* in the pre-split-share reform period (year −3 to year −1), in which year 0 indicates the year during which the firm underwent the split-share reform.
BEFORE_INV	Mean *INV* in the pre-split-share reform period (year −3 to year −1), in which year 0 indicates the year during which the firm underwent the split-share reform.
NTS_FRACTION	The fraction of non-tradable shares in a firm prior to the split-share structure reform
SPLIT_SHARE_REFORM (indicator)	An indicator variable that takes the value of one if the split-share structure reforms were implemented in the previous year, and zero otherwise

Panel B: Effect of non-tradable shares on stock liquidity

	Dep. var.: *LIQ*	Dep. var.: *NTS_FRACTION*	Dep. var.: *LIQ*
Variables	(1)	(2)	(3)
NTS_FRACTION	−0.229***		
	(0.055)		
SPLIT_SHARE_REFORM (indicator)		−0.110**	0.029***
		(0.046)	(0.008)
LOGASSET	0.166***	0.001	0.071***
	(0.012)	(0.011)	(0.003)
Q	0.032**	0.041***	0.013***
	(0.016)	(0.011)	(0.003)
SD_CFO	−0.144	0.137	0.046
	(0.243)	(0.152)	(0.054)
SD_SALE	−0.027	0.119**	−0.046***
	(0.071)	(0.056)	(0.016)
SD_INV	0.208*	−0.177	0.008
	(0.110)	(0.109)	(0.030)
Z	0.005	−0.004**	0.001**
	(0.003)	(0.002)	(0.001)
TANG	0.039	0.055	0.009
	(0.076)	(0.055)	(0.018)
KSTR	−0.085	0.029	−0.092***
	(0.069)	(0.054)	(0.019)
IND_KSTR	0.176	0.074	−0.175**
	(0.294)	(0.258)	(0.074)
CFO_SALE	0.030	−0.014	0.010
	(0.032)	(0.025)	(0.007)
SLACK	0.000	0.001	−0.000
	(0.001)	(0.001)	(0.000)
DIV	0.030	0.028*	0.033***
	(0.022)	(0.015)	(0.004)
AGE	−0.000	−0.011***	0.000
	(0.002)	(0.002)	(0.000)
OPERATINGCYCLE	−0.000	0.001	−0.001
	(0.011)	(0.010)	(0.003)
LOSS	−0.047	−0.014	−0.033***
	(0.035)	(0.030)	(0.006)
CASH	−0.023	−0.008	0.041*
	(0.096)	(0.063)	(0.021)
ANALYSTS	0.005	−0.008**	−0.003***
	(0.004)	(0.004)	(0.000)
CONSTANT	−3.852***	0.510*	−1.905***
	(0.305)	(0.269)	(0.070)
Industry FE	Y	Y	Y
Year FE	Y	Y	Y
Observations	772	600	13,299
R-squared	0.466	0.192	0.609

(*continued on next page*)

Table 6 (*continued*)

Panel C: Pre-match propensity score regression and post-match diagnostic regression

	Dummy = 1 if in treated group and 0 if in control group	
	Before matching	After matching
Variables	(1)	(2)
LIQ	−4.650***	0.358
	(0.394)	(0.762)
LOGASSET	−0.202	0.078
	(0.143)	(0.268)
Q	0.423***	−0.010
	(0.140)	(0.230)
SD_CFO	2.108	1.153
	(1.964)	(3.531)
SD_SALE	−0.439	−1.597
	(0.668)	(1.443)
SD_INV	−1.618	3.677
	(1.558)	(3.814)
Z	0.001	0.028
	(0.022)	(0.040)
TANG	−0.363	0.818
	(0.642)	(1.133)
KSTR	−0.138	−0.262
	(0.568)	(0.972)
IND_KSTR	−5.432	3.012
	(7.013)	(31.243)
SLACK	−0.012	0.073
	(0.018)	(0.074)
OPERATINGCYCLE	0.026	−0.046
	(0.104)	(0.186)
CASH	0.678	0.764
	(0.915)	(1.932)
DIV	0.077	0.132
	(0.170)	(0.293)
LOSS	−0.394*	−0.143
	(0.217)	(0.423)
BEFORE_INVEFF	−8.710	42.446
	(8.473)	(28.282)
BEFORE_INV	11.320	−44.892
	(8.258)	(27.656)
CONSTANT	−0.535	−2.892
	(3.926)	(10.604)
Industry FE	Y	Y
Year FE	Y	Y
Observations	711	132
p-value of χ^2	0.000	0.996
Pseudo R-squared	0.520	0.064

Panel D: Estimated propensity score distributions

Propensity scores	Min	P5	P50	Mean	SD	P95	Max
Treated	0.046	0.135	0.422	0.473	0.252	0.953	0.993
Control	0.047	0.134	0.424	0.475	0.255	0.971	0.999
Difference	0.000	0.000	0.002	0.003	0.004	0.015	0.019

Panel E: Differences in pre-split-share reform characteristics

Variables	Treated	Control	Difference	*t*-statistic
LIQ	−0.589	−0.592	0.003	0.120
LOGASSET	20.960	20.963	−0.003	−0.031
Q	1.137	1.027	0.111	0.545
SD_CFO	0.065	0.063	0.002	0.278
SD_SALE	0.131	0.132	−0.001	−0.041
SD_INV	0.066	0.062	0.004	0.506
Z	3.018	2.516	0.502	0.498
TANG	0.293	0.304	−0.011	−0.356
KSTR	0.237	0.249	−0.012	−0.381
IND_KSTR	0.244	0.245	−0.001	−0.174

(*continued on next page*)

Table 6 (*continued*)

Panel E: Differences in pre-split-share reform characteristics

Variables	Treated	Control	Difference	*t*-statistic
SLACK	1.575	0.904	0.670	1.293
OPERATINGCYCLE	5.153	5.241	−0.089	−0.509
CASH	0.134	0.111	0.023	1.268
DIV	0.394	0.348	0.045	0.597
LOSS	0.121	0.152	−0.030	−0.469
BEFORE_I_DEV	−0.018	−0.012	−0.006	−0.757
BEFORE_INV	0.012	0.019	−0.007	−0.829

Panel F: Univariate difference-in-differences test

Subsample	Variable	Mean treated difference (After – Before)	Mean control difference (After – Before)	Mean DiD estimator (Treated – Control)	*t*-statistic for DiD estimator
Full sample	*Avg. INV*	0.001	−0.011	0.012	0.853
		(0.009)	(0.011)	(0.014)	
	Avg. INVEFF	0.003	0.006	0.003	0.347
		(0.005)	(0.006)	(0.009)	
Under-investing firms	*Avg. INV*	0.004	−0.030**	0.034**	2.246
		(0.012)	(0.011)	(0.015)	
	Avg. INVEFF	0.007	−0.017	0.025*	1.747
		(0.009)	(0.011)	(0.014)	
Over-investing firms	*Avg. INV*	−0.005	0.017	−0.022	−0.843
		(0.012)	(0.021)	(0.026)	
	Avg. INVEFF	−0.003	−0.006	0.003	0.199
		(0.010)	(0.011)	(0.016)	

Panel G: Multivariate difference-in-differences test

	Dep. var.: *INV*			Dep. var.: *INVEFF*		
	Full sample	Under-investing subsample	Over-investing subsample	Full sample	Under-investing subsample	Over-investing subsample
Variables	(1)	(2)	(3)	(4)	(5)	(6)
TREAT×*BEFORE*$^{-1}$	0.018	0.001	0.052***	0.006	0.010	−0.005
	(0.017)	(0.018)	(0.013)	(0.019)	(0.007)	(0.034)
TREAT×*CURRENT*	0.010	0.009	0.017*	−0.028***	−0.019**	−0.045***
	(0.007)	(0.007)	(0.010)	(0.006)	(0.008)	(0.012)
TREAT×*AFTER*^{1}	0.031*	0.041**	0.016	−0.023**	−0.022	−0.018
	(0.017)	(0.017)	(0.027)	(0.010)	(0.016)	(0.013)
TREAT×*AFTER*^{23}	0.031***	0.006	0.063***	0.000	0.017*	−0.030**
	(0.011)	(0.007)	(0.021)	(0.009)	(0.010)	(0.013)
BEFORE^{-1}	−0.006	−0.001	−0.022***	−0.013	−0.005	−0.026
	(0.014)	(0.020)	(0.008)	(0.015)	(0.006)	(0.028)
CURRENT	−0.022***	−0.018**	−0.034***	0.000	0.000	−0.001
	(0.006)	(0.008)	(0.010)	(0.005)	(0.004)	(0.014)
AFTER^{1}	−0.015	−0.016	−0.018	0.013	0.003	0.028**
	(0.011)	(0.013)	(0.026)	(0.010)	(0.013)	(0.012)
AFTER^{23}	−0.015**	−0.012**	−0.023	−0.002	−0.011*	0.014
	(0.008)	(0.006)	(0.018)	(0.005)	(0.006)	(0.012)
TREAT	−0.020***	−0.014**	−0.033***	0.013***	0.006	0.036**
	(0.006)	(0.006)	(0.009)	(0.004)	(0.004)	(0.014)
CONSTANT	−0.002	−0.007	0.010	−0.026***	−0.036***	−0.027***
	(0.004)	(0.005)	(0.008)	(0.005)	(0.010)	(0.009)
Industry FE	Y	Y	Y	Y	Y	Y
Observations	791	490	301	790	514	276
R-squared	0.054	0.064	0.084	0.140	0.156	0.224

This table presents the results of DiD analyses that examine how an exogenous shock to stock liquidity due to the split-share structure reform affects firm investment and investment efficiency. Panel A provides variable definitions for new variables used in the DiD analyses. All remaining variables are defined in Table 1. Panel B demonstrates the effect of non-tradable shares and the split-share structure reform on stock liquidity of sample firms consisting of non-financial firms with non-missing data in the CSMAR and Wind databases between the years 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. To arrive at the DiD sample, firms are sorted into terciles based on their change in stock liquidity from the pre-split-share structure reform period to the post-split-share structure reform period. Firms in the top tercile (middle and bottom terciles) constitute the treated (control) group. Each treated firm is matched to a control firm by propensity score matching with the nearest neighborhood algorithm, without replacement. Panel C presents estimates from the probit model for the pre-matched sample (Column (1)) and post-matched sample (Column (2)). The dependent variable is an indicator variable that takes the value of one (zero) if the firm belongs to the treated group (control

group). Industry and year fixed effects are included in both columns. Panel D reports the distribution of estimated propensity scores for the treated firms, control firms, and the difference in estimated propensity scores for the matched sample. Panel E reports the mean values of firm characteristics of the treated and control firms, the difference between them, and the corresponding *t*-statistics. Panel F presents the univariate DiD test results. The differences in the three-year average *INV(INVEFF)* between the post- and pre-reform periods are reported for both treated and control groups. Standard errors are reported in parentheses below the mean differences in investment measures. The mean DiD estimator and the corresponding *t*-statistics are also reported. Panel G reports regressions results of investment-related measures surrounding the split-share structure reform. The dependent variable is *INV(INVEFF)* measured one year after the adoption of the split-share structure reform in columns (1)–(3) (columns (4)–(6)). Robust standard errors clustered by year are reported in parentheses below the coefficient estimates. In Panels F and G, the under-investing (over-investing) firms are identified as firms that have a positive (negative) under-investment propensity (*UNDER_PROP*) when examining *INV* and a negative (positive) deviation from expected rate of investment when examining *INVEFF*, respectively. In all panels, superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

split-share structure reform, as seen from the positive (negative) and significant coefficient of $TREAT \times AFTER$[23]. In summary, these results confirm our claim that stock liquidity improves investment efficiency only for under-investing firms.

4.2.2. Change regression

To overcome reverse causality concerns, we followed the methods used by Fang et al. (2009) and Edmans et al. (2013) and estimated the effect of a change in stock liquidity with respect to the split-share structure reform on investment efficiency. Using two-change regression specifications, we examined whether a change in stock liquidity influences the degree of investment efficiency, measured as the deviation from the expected investment rate multiplied by −1 using the full sample and subsamples of under- and over-investing firms.[18] The specifications used were as follows:

$$INV_{i,t+2} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + cUNDER\_PROP_{i,t} + d\Delta LIQ_{i,t-1\ to\ t+1} \times UNDER\_PROP_{i,t} + e^{'}\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}; \quad (6)$$

$$INVEFF_{i,t+2} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + c^{'}\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}. \quad (7)$$

The estimated results of the change regression described in Eqs. (6) and (7) are presented in Panel A of Table 7. The results in the first three columns, based on the conditional specification of investment, show that the interaction term between the change in stock liquidity ($\Delta LIQ_{i,t-1\ to\ t+1}$) and under-investment propensity measured in three different ways is positive and significant at the 1% level. This suggests that firms with greater under-investment propensity are likely to increase their investment with the increase in liquidity brought on by the split-share structure reform. In Columns (4)–(6), we regressed *INVEFF* on the changes in stock liquidity for the full sample (Column (4) and the under- and over-investing subsamples (Columns (5) and (6), respectively). We found that the coefficient on $\Delta LIQ_{i,t-1\ to\ t+1}$ was negative only in Column (5), i.e., among the subsample of under-investing firms. These findings confirmed that stock liquidity has a positive causal effect on investment efficiency, but only for under-investing firms.

We also conducted a placebo test in which we assumed that the split-share structure reform took place a year before it occurred. Using this placebo year of reform, we computed the changes in the measures as specified in Eqs. (6) and (7), and repeated the above analysis. Panel B of Table 7 presents the findings using placebo reforms, and we found no evidence to support the view that investment efficiency, especially that of under-investing firms, changed in the year prior to the reform in any significant manner.

4.2.3. Announcement reactions to split-share structure reform

To the extent that the split-share structure reform increases firms' investment efficiency, it should have a value-increasing effect on the firm, especially in the case of under-investing firms that stand to benefit most from the reform. To examine the valuation effects, we computed the abnormal returns when the stock resumes trading after the compensation payment is negotiated with shareholders. Daily abnormal stock returns (*AR*) were calculated using a market model. Market model parameters were estimated using 220 trading days of return data ending 61 days before the announcement, using the return on the Shanghai Composite Index as a proxy for market return. *AR*s were accumulated to obtain the *CAR* from day 1 of trading resumption to days 2 and 5 after trading resumption, respectively, to obtain $CAR(1,2)$ and $CAR(1,5)$.

Table 8 presents the results of the event study approach applied to a sample of 351 reform-related trading resumptions. Panel A contains the mean and median abnormal returns estimated on trading resumption days ($AR(1)$), $CAR(1,2)$, and $CAR(1,5)$. We also split the sample into under- and over-investing firms according to the sign of the deviation in investment from the expected investment rate. First, we found that all announcement returns in the full sample were positive: $AR(1)$, $CAR(1,2)$, and $CAR(1,5)$ were 3.2%, 4.3%, and 6.2%, respectively, and were significant at the 1% level. These results suggested that shareholders react positively to the finalization or agreement with the split-share structure reform process. Furthermore, announcement reactions were stronger for under-investing firms than for over-investing firms, with the mean and median differences being 1.7% and 1.9% (2.0% and 1.9%) for $AR(1)$ ($CAR(1,2)$), respectively, which were significant at the 5% or lower level.

In Panel B of Table 8, we used a multivariate specification $AR(1)(CAR(1,\ t_2)) = a + bUNDER\_INVESTING(UNDER\_PROP) + c^{'}\boldsymbol{Controls} + \epsilon$ to examine the announcement reactions in Columns (1)–(4). We also included the control variables listed in Table 3.

[18] We omitted year fixed effects, as all the variables, including the controls, were computed for all the firms as changes with respect to the split-shock structure reform initiated in 2005 for most of the firms.

Table 7
Effect of the change in liquidity around split-share structure reform on investment efficiency.

Panel A: Investment efficiency around split-share structure reform years

	Dep. var.: *INV*			Dep. var.: *INVEFF*		
	Under-investment propensity measured using			Full sample	Under-investing subsample	Over-investing subsample
	Firm-level cash & leverage	Full sample residual	Industry-year residual			
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	−0.029***	−0.096***	−0.099***	0.032**	0.016*	0.038
	(0.006)	(0.012)	(0.016)	(0.014)	(0.009)	(0.027)
UNDER_PROP	0.003***					
	(0.001)					
UNDER_AGGPROP		−0.004***				
		(0.001)				
UNDER_INDPROP			−0.004***			
			(0.001)			
ΔLIQ × UNDER_PROP	0.003*					
	(0.002)					
ΔLIQ × UNDER_AGGPROP		0.012***				
		(0.002)				
ΔLIQ × UNDER_INDPROP			0.012***			
			(0.003)			
ΔLOGASSET	0.042***	0.040***	0.040***	0.010	0.008***	−0.028
	(0.014)	(0.015)	(0.015)	(0.008)	(0.001)	(0.022)
ΔQ	0.006***	0.005**	0.006**	−0.003*	−0.000	−0.003
	(0.002)	(0.002)	(0.003)	(0.002)	(0.001)	(0.005)
ΔZ	−0.000	−0.000	−0.000	0.001	0.000**	0.001
	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
ΔTANG	−0.100*	−0.093*	−0.098*	0.026	−0.052***	0.117***
	(0.051)	(0.053)	(0.054)	(0.025)	(0.016)	(0.045)
ΔKSTR	0.148***	0.131***	0.131***	−0.056***	0.025*	−0.134***
	(0.023)	(0.023)	(0.023)	(0.019)	(0.013)	(0.043)
ΔCFO_SALE	−0.017	−0.015	−0.014	0.008	−0.008	0.014
	(0.017)	(0.018)	(0.018)	(0.008)	(0.006)	(0.029)
ΔSLACK	−0.000	−0.001	−0.001	−0.000	−0.001***	0.000
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
ΔDIV	−0.014***	−0.014***	−0.014***	0.011***	−0.000	0.027***
	(0.004)	(0.004)	(0.004)	(0.002)	(0.002)	(0.008)
ΔOPERATINGCYCLE	−0.020**	−0.019*	−0.019*	0.019***	0.004	0.039*
	(0.009)	(0.010)	(0.010)	(0.005)	(0.003)	(0.021)
ΔLOSS	−0.018***	−0.021***	−0.021***	−0.004	−0.016**	0.023**
	(0.003)	(0.004)	(0.004)	(0.006)	(0.006)	(0.010)
ΔCASH	0.029	0.058	0.057	0.015	0.032*	0.049
	(0.031)	(0.037)	(0.037)	(0.023)	(0.019)	(0.057)
ΔANALYSTS	0.002	0.001	0.001	0.001**	0.001***	0.001
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
CONSTANT	0.009**	0.033***	0.036***	−0.065***	−0.057***	−0.078***
	(0.004)	(0.004)	(0.006)	(0.008)	(0.006)	(0.013)
Observations	922	922	922	922	563	359
R-squared	0.092	0.096	0.096	0.042	0.084	0.097

Panel B: Placebo tests

	Dep. var.: *INV*			Dep. var.: *INVEFF*		
	Under-investment propensity measured using			Full sample	Under-investing subsample	Over-investing subsample
	Firm-level cash & leverage	Full sample residual	Industry-year residual			
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	0.012*	−0.065	−0.071	−0.038***	−0.003	−0.121***
	(0.007)	(0.052)	(0.049)	(0.010)	(0.006)	(0.031)
UNDER_PROP	0.003**					
	(0.001)					
UNDER_AGGPROP		−0.003***				
		(0.001)				
UNDER_INDPROP			−0.004**			

(*continued on next page*)

Table 7 (*continued*)

Panel B: Placebo tests						
	Dep. var.: *INV*			Dep. var.: *INVEFF*		
	Under-investment propensity measured using			Full sample	Under-investing subsample	Over-investing subsample
	Firm-level cash & leverage	Full sample residual	Industry-year residual			
Variables	(1)	(2)	(3)	(4)	(5)	(6)
			(0.002)			
ΔLIQ × *UNDER_PROP*	0.005					
	(0.004)					
ΔLIQ × *UNDER_AGGPROP*		0.013				
		(0.008)				
ΔLIQ × *UNDER_INDPROP*			0.016			
			(0.012)			
Controls in Panel A	Yes	Yes	Yes	Yes	Yes	Yes
Observations	885	885	885	884	618	266
R-squared	0.050	0.050	0.053	0.029	0.067	0.116

This table presents estimates of the pooled OLS regressions of investment efficiency on the change in stock liquidity around the split-share structure reform (Panel A) and in a placebo year prior to the pre-split share structure reform (Panel B). The sample consists of non-financial firms that have non-missing data in the CSMAR and Wind databases between the years 2002 and 2016 and that experienced the split-share structure reform during this period. Firms that are relegated to the special treatment (ST) category are excluded. The specifications in both the panels are identical. However, the dependent and explanatory variables are measured in Panel A around split-share structure reform year while in Panel B they are measured three years prior to the split-share structure reform. In both panels, columns (1)–(3) report results of the model: $INV_{i,t+2} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + cUNDER\_PROP_{i,t} + d\Delta LIQ_{i,t-1\ to\ t+1} \times UNDER\_PROP_{i,t} + e'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}$. Columns (4)–(6) report the OLS regression results of the model: $INVEFF_{i,t+2} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + c'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}$. In column (3) (column (4)), the model is estimated using the subsample of under-investing firms (over-investing firms), which are identified as those firms that have a negative (positive) deviation from expected rate of investment. In both Panels, Δdenotes the change in each variable from the fiscal year before the (pseudo) split-share reform i.e., year $t-1$ to the fiscal year after the (pseudo) split-share reform i.e., year $t+1$, with t indicating the year during which the firm underwent the split-share reform (three years prior to the year when the firm underwent the split-share structure reform). Robust standard errors clustered by industry are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

In Columns (1) and (2), with $AR(1)$ and $CAR(1,\ 2)$ as dependent variables, we found that the coefficient of *UNDER__INVESTING* (an indicator variable that takes the value of one for firms with negative deviations in investment from the expected rate) was positive and significant. Because there could be an element of look-ahead bias in classifying firms according to the post-announcement classification into under- and over-investing firms, we re-estimated the regressions using *UNDER__PROP* as the independent variable. *UNDER__PROP* is an indicator variable based on the *ex ante* probability of a firm under-investing. Our results remained qualitatively the same.

5. Further analyses

5.1. Testing channels

In this subsection, we examine various plausible channels through which stock liquidity improves investment efficiency, especially those through which it reduces the under-investment problem, that is, channels of improved corporate governance, enhanced feedback effect, and relaxed financing constraints. As discussed in Section 2, an increase in institutional ownership can facilitate firm monitoring and serve as a disciplining mechanism, leading to an improvement in investment efficiency (i.e., a reduction in both under- and over-investment problems). In addition, an increase in price efficiency can reduce information asymmetry and lower the cost of capital, thereby reducing under-investment problems. Moreover, a reduction in financing constraints can reduce financing costs and improve access to internal and external funding sources, thereby attenuating under-investment problems.

To evaluate these channels, we examined whether the changes in the aforementioned channel variables (i.e., institutional ownership, price efficiency, and financing constraints) driven by liquidity changes surrounding the split-share structure reform can account for the improvement in investment efficiency (using the full sample), reduction in under-investment (using the subsample of under-investing firms), and reduction in over-investment (using the subsample of over-investing firms). Regarding the model specifications, we employed the two-stage least squares (2SLS) change regression framework (instead of the DiD framework), which allows us to use a relatively larger sample. The first- and second-stage regression models were as follows:

$$\Delta Channel_{i,t-1\ to\ t+1} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + c'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \Delta e_{i,t-1\ to\ t+1}; \tag{8}$$

$$INVEFF_{i,t+2} = a + b\Delta\widehat{Channel}_{i,t-1\ to\ t+1} + c'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}. \tag{9}$$

Table 8
Announcement effects of the split-share structure reform: under-investing firms versus over-investing firms.

Panel A: Univariate analysis of split-share structure reform announcements

	Full sample ($N = 351$)		Under-investing subsample ($N = 220$)		Over-investing subsample ($N = 122$)		Test of difference: Under – Over	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
AR (1)	3.199***	4.144***	3.712***	4.842***	2.022***	2.942***	1.691***	1.900***
	(10.61)	(9.20)	(10.18)	(8.37)	(3.75)	(3.57)	(2.67)	(2.67)
CAR (1, 2)	4.291***	4.793***	4.872***	5.037***	2.854***	3.147***	2.018**	1.890**
	(9.89)	(9.03)	(9.11)	(8.01)	(3.81)	(3.74)	(2.22)	(2.16)
CAR (1, 5)	6.219***	5.369***	6.918***	6.762***	4.540***	2.985***	2.378*	3.777**
	(9.75)	(8.89)	(8.89)	(8.04)	(3.98)	(3.49)	(1.77)	(2.22)

Panel B: Multivariate analysis of split-share structure reform announcements

	OLS regression of announcement returns			
	Dep. var.: *AR (1)*	Dep. var.: *CAR (1, 2)*	Dep. var.: *AR (1)*	Dep. var.: *CAR (1, 2)*
Variables	(1)	(2)	(3)	(4)
UNDER_INVESTING (indicator)	0.015***	0.018*		
	(0.003)	(0.007)		
UNDER_PROP (indicator)			0.004*	0.005*
			(0.001)	(0.002)
Controls in Table 3	Y	Y	Y	Y
Observations	342	342	344	344
R-squared/Log likelihood	0.122	0.126	0.116	0.123

This table presents univariate and multivariate analyses of announcement returns of the split-share structure reform separately for under-investing firms and over-investing firms. The sample consists of 351 reform announcements of Chinese firms with non-missing data in the CSMAR and Wind databases between the years 2002 and 2016. Firms that are relegated to the special treatment (ST) category are excluded. In Panel A, summary statistics of cumulative abnormal returns during the reform announcement are provided. Since trading is suspended during the announcement and subsequent negotiations with shareholders, announcement reactions are estimated as of trading resumption. The abnormal stock returns are calculated using the market model. All the model parameters are estimated using 220 trading days of return data beginning 280 days before and ending 61 days before the reform announcement. The Shanghai composite index is used as a proxy for the market return. The daily abnormal stock returns (AR) are cumulated to obtain the cumulative abnormal returns (CAR) from day 1 after the reform announcement date to day t_2 after the announcement. The sample is split into subsamples of under-investing and over-investing firms, which are identified as firms that have a negative (positive) deviation from expected rate of investment, respectively. *t*-statistics are reported in parentheses below AR or CAR estimates. Panel B reports the results of the model $AR(1)(CAR(1,t_2)) = a + b UNDER\_INVESTING\ (UNDER\_PROP) + c' \boldsymbol{Controls} + \epsilon$, where *UNDER_INVESTING* is an indicator variable that takes the value of one for firms with negative deviation from expected rate of investment in the previous fiscal year, and zero otherwise. All the explanatory variables are measured as of the latest completed fiscal year. Robust standard errors clustered by industry are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The channel variable ($\Delta Channel_{i,t-1\ to\ t+1}$) in the improved corporate governance channel is the change in institutional ownership surrounding the split-share structure reform, $\Delta IO_{i,t-1\ to\ t+1}$, where institutional ownership is computed as the total proportion of shares outstanding held by institutional investors aggregated by the Wind database (i.e., institutional investors, including mutual funds, securities companies, qualified foreign institutional investors, insurers, banks, and pension funds). The channel variable in the enhanced feedback effect channel is the change in price efficiency surrounding the split-share structure reform, $\Delta PE_{i,t-1\ to\ t+1}$, where price efficiency is computed as minus one time the absolute value of the correlation between contemporaneous weekly stock returns and one-week lagged weekly stock returns. The channel variable in the financing constraint channel is the change in the financing constraint measure proposed by Hadlock and Pierce (2010), that is, the HP index surrounding the split-share structure reform, $\Delta HP_{i,t-1\ to\ t+1}$, where the HP index is computed as $-0.737Size + 0.043Size^2 - 0.040Age$, where *Size* is defined as the natural logarithm of total assets and *Age* is defined as the number of years elapsed since the listing date.

Table 9 presents the 2SLS change regression analysis. Columns (1) and (2), (3) and (4), and (5) and (6) of Table 9 report the first- and second-stage estimation results based on the full sample, the subsample of under-investing firms, and the subsample of over-investing firms, respectively.[19] Panel A of Table 9 reports the estimation results for *improved corporate governance* channels. The first-stage regressions in Panel A show that an increase in stock liquidity surrounding the split-share structure reform is associated with

[19] Under-investing firms (over-investing firms) are identified as firms that have a negative (positive) deviation from expected rate of investment in year $t + 2$.

Table 9
Testing the channels of corporate governance, feedback effects, and financing constraints.

Panel A: Improved corporate governance channel

	Full Sample		Under-investing subsample		Over-investing subsample	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	Dep. var.: ΔIO	*Dep. var.: INVEFF*	*Dep. var.: ΔIO*	*Dep. var.: INVEFF*	*Dep. var.: ΔIO*	*Dep. var.: INVEFF*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	0.324***		0.272***		0.375***	
	(0.052)		(0.068)		(0.082)	
$\widehat{\Delta IO}$		0.094***		0.059**		0.101*
		(0.031)		(0.026)		(0.061)
Controls in Table 7	Y	Y	Y	Y	Y	Y
Observations	932	922	563	563	359	359
R-squared	0.125	0.205	0.125	0.406	0.186	0.280

Panel B: Enhanced feedback effect channel

	Full Sample		Under-investing subsample		Over-investing subsample	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	Dep. var.: ΔPE	*Dep. var.: INVEFF*	*Dep. var.: ΔPE*	*Dep. var.: INVEFF*	*Dep. var.: ΔPE*	*Dep. var.: INVEFF*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	0.066***		0.048***		0.096***	
	(0.014)		(0.018)		(0.024)	
$\widehat{\Delta PE}$		0.453***		0.326*		0.366
		(0.163)		(0.172)		(0.228)
Controls in Table 7	Y	Y	Y	Y	Y	Y
Observations	913	903	550	550	353	353
R-squared	0.045	0.117	0.050	0.230	0.085	0.318

Panel C: Relaxed financing constraint channel

	Full Sample		Under-investing subsample		Over-investing subsample	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	Dep. var.: ΔHP	*Dep. var.: INVEFF*	*Dep. var.: ΔHP*	*Dep. var.: INVEFF*	*Dep. var.: ΔHP*	*Dep. var.: INVEFF*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	−0.032**		−0.025*		−0.092***	
	(0.016)		(0.014)		(0.032)	
$\widehat{\Delta HP}$		−0.814*		−0.645		−0.411
		(0.424)		(0.449)		(0.288)
Controls in Table 7	Y	Y	Y	Y	Y	Y
Observations	932	922	563	563	359	359
R-squared	0.927	−1.053	0.963	−0.429	0.878	0.020

This table presents estimates of the two-stage least squares (2SLS) regressions designed to examine corporate governance, feedback, and financing constraint channels. The sample consists of non-financial firms that have non-missing data in the CSMAR and Wind databases between the years 2002 and 2016 and that experienced the split-share reform during this period. Firms that are relegated to the special treatment (ST) category are excluded. The first-stage regression model is specified as follows: $\Delta Channel_{i,t-1\ to\ t+1} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + c'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \Delta e_{i,t-1\ to\ t+1}$. The second-stage regression model is specified as follows: $INVEFF_{i,t+2} = a + b\Delta\widehat{Channel}_{i,t-1\ to\ t+1} + c'\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}$. The channel variable ($\Delta Channel_{i,t-1\ to\ t+1}$) in Panel A is the change in institutional ownership surrounding the split-share structure reform, $\Delta IO_{i,t-1\ to\ t+1}$, where institutional ownership is computed as the total proportion of shares outstanding held by institutional investors aggregated by the Wind database (i.e., institutional investors that include mutual funds, securities companies, qualified foreign institutional investors, insurers, banks, and pension funds). The channel variable in Panel B is the change in price efficiency surrounding the split-share structure reform, $\Delta PE_{i,t-1\ to\ t+1}$, where price efficiency is computed as minus one time the absolute value of the correlation between contemporaneous weekly stock returns and the one week lagged weekly stock returns. The channel variable in Panel C is the change in a financing constraint measure proposed by Hadlock and Pierce (2010), i.e., HP index, surrounding the split-share structure reform, $\Delta HP_{i,t-1\ to\ t+1}$, where the HP index is computed as $-0.737Size + 0.043Size^2 - 0.040Age$, where *Size* is defined as the natural logarithm of total assets and *Age* is defined as the number of years elapsed since the listing date. In columns (1) and (2), the model is estimated using the full sample. In columns (3) and (4) (columns (5) and (6)) of all the panels, the model is estimated using the subsample of under-investing firms (over-investing firms), where under-investing firms (over-investing firms) are identified as firms that have a negative (positive) deviation from expected rate of investment in year $t + 2$. Δ denotes the change in each variable from the fiscal year before the split-share reform (year $t - 1$) to the fiscal year after the split-share reform (year $t + 1$), with t indicating the year during which the firm underwent the split-share structure reform. Standard errors are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

an overall increase in institutional ownership surrounding the reform in the full sample and in the subsamples of under- and over-investing firms, suggesting that under- and over-investing firms with more liquid stocks tend to have a higher level of institutional ownership than their counterparts with low stock liquidity. These results indicate that higher stock liquidity tends to be associated with better corporate governance because institutional investors tend to be better at monitoring firms (Hartzell and Starks, 2003; Edmans, 2014). The second-stage regressions in Panel A also indicate that the change in institutional ownership generated by the change in stock liquidity is positively associated with the level of investment efficiency, and that the positive association is more significant among under-investing firms than among over-investing firms. This finding is consistent with the prediction that governance executed through institutional ownership is likely to be more successful in mitigating under-investment than over-investment.

Panel B of Table 9 presents the estimated results for the *enhanced feedback effect* channel. The first-stage regressions in Panel B show that an increase in price efficiency is positively associated with an increase in stock liquidity in the full sample and in the under-and over-investing subsamples, suggesting that stock prices become more efficient when stocks are more liquid. The second-stage regressions in Panel B indicate that the change in price efficiency generated by the change in stock liquidity is positively associated with an increase in investment efficiency in the full sample and in the subsample of under-investing firms, but not in the subsample of over-investing firms. To the extent that under-investing firms forego positive net present value projects because of the information asymmetry between managers and investors, an increase in price efficiency due to an increase in stock liquidity can help managers make better-informed investment decisions by facilitating efficient feedback from stock prices.

Panel C of Table 9 reports the estimation results for the *relaxed financing constraints* channel. The first-stage regressions in Panel C show that the increase in stock liquidity is negatively associated with the increase in financing constraints, as measured by the HP index in the full sample and the under-and over-investing subsamples, suggesting that both under- and over-investing firms tend to be less financially constrained when stocks are more liquid. The second-stage regressions in Panel C indicate that the negative association between the change in the degree of financing constraints generated by the change in stock liquidity and the magnitude of investment efficiency is significant in the full sample but insignificant in both subsamples. To the extent that under-investing firms forego positive net present value projects because of financing constraints, the relaxation of financing constraints due to an increase in stock liquidity is more likely to improve the investment efficiency of under-investing firms than that of over-investing firms. The positive effect of relaxed financing constraints on investment efficiency is found in the full sample but not in the two subsamples, which might be attributed to the small sample sizes in the subsamples.

Given that we obtained somewhat weak results for the relaxed financing constraints channel, we tested the retained earnings and external financing channels as a further check on the relaxed financing constraints channel. Chinese firms are often financially constrained, which leads to under-investment. An increase in stock liquidity can improve access to both internal and external funding and reduce external financing costs. Thus, we examined whether an increase in stock liquidity surrounding the split-share structure reform is associated with an increase in retained earnings and external financing, leading to an improvement in investment efficiency. We respecified the 2SLS regression models to test the retained earnings and external financing channels.The channel variable ($\Delta Channel_{i,t-1\ to\ t+1}$) in the retained earnings channel is the change in the retained earnings measure surrounding the split-share structure reform, $\Delta RE_{i,t-1\ to\ t+1}$. The retained earnings measure is computed as the amount of retained earnings on the balance sheet divided by the book's total assets at the beginning of the fiscal year. The channel variable in the external financing channel is the change in an external financing measure surrounding the split-share structure reform, $\Delta EF_{i,t-1\ to\ t+1}$, where the external financing measure is computed as the total external financing amounts (i.e., proceeds from obtaining bank loans and issuing bonds and stocks) divided by total book assets at the beginning of the year.

Table 10 presents the 2SLS regression results. The first-stage regressions in Panel A show that an increase in stock liquidity is positively associated with a change in retained earnings in the full sample and in the under- and over-investing subsamples, suggesting that both under- and over-investing firms tend to have more retained earnings when stocks are more liquid. The second-stage regressions in Panel A indicate that the positive association between the change in retained earnings generated by the change in stock liquidity and the magnitude of investment efficiency is significant in the full sample but insignificant in both subsamples. Similarly, the first-stage regressions in Panel B show that an increase in stock liquidity is positively associated with a change in external financing in the full sample and in the under- and over-investing subsamples, suggesting that both under-investing and over-investing firms tend to obtain more external financing when their stocks are more liquid. The second-stage regressions in Panel B indicate that the positive association between the change in external financing generated by the change in stock liquidity and the magnitude of investment efficiency is significant in the full sample but insignificant in both subsamples.

To the extent that under-investing firms forego positive net present value projects due to financing constraints, the increases in retained earnings and external financing due to an increase in stock liquidity are more likely to improve the investment efficiency of under-investing firms as compared to that of over-investing firms. The positive effect of increased retained earnings and external financing on investment efficiency found in the full sample but not in the two subsamples might be attributed to the small sample sizes in the subsamples.

In summary, the results in Tables 9 and 10 show that when stock liquidity increases, an increase in institutional ownership and price efficiency, and a decrease in financial constraints can help improve the investment efficiency of firms that are more prone to *under-invest*.

5.2. Robustness tests

To confirm the validity of our main findings, we performed a range of robustness tests, the results of which are presented upon

Table 10
Testing retained earnings and external financing channels.

Panel A: Retained earnings channel

	Full Sample		Under-investing subsample		Over-investing subsample	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	Dep. var.: ΔRE	*Dep. var.: INVEFF*	*Dep. var.: ΔRE*	*Dep. var.: INVEFF*	*Dep. var.: ΔRE*	*Dep. var.: INVEFF*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	0.143***		0.103**		0.138***	
	(0.039)		(0.051)		(0.053)	
$\widehat{\Delta RE}$		0.182*		0.108		0.138
		(0.098)		(0.080)		(0.166)
Controls in Table 7	Y	Y	Y	Y	Y	Y
Observations	932	922	563	563	359	359
R-squared	0.125	0.205	0.125	0.406	0.186	0.280

Panel B: External financing channel

	Full Sample		Under-investing subsample		Over-investing subsample	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	Dep. var.: ΔEF	*Dep. var.: INVEFF*	*Dep. var.: ΔEF*	*Dep. var.: INVEFF*	*Dep. var.: ΔEF*	*Dep. var.: INVEFF*
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔLIQ	0.445***		0.508**		0.106**	
	(0.137)		(0.208)		(0.048)	
$\widehat{\Delta EF}$		0.045*		0.019		0.181
		(0.024)		(0.015)		(0.220)
Controls in Table 7	Y	Y	Y	Y	Y	Y
Observations	879	870	528	528	342	342
R-squared	0.239	0.119	0.345	0.390	0.374	0.276

This table presents estimates of the two-stage least squares (2SLS) regressions designed to perform tests on retained earnings and external financing channels. The sample consists of non-financial firms that have non-missing data in the CSMAR and Wind databases between the years 2002 and 2016 and that experienced the split-share reform during this period. Firms that are relegated to the special treatment (ST) category are excluded. The first-stage regression model is specified as follows: $\Delta Channel_{i,t-1\ to\ t+1} = a + b\Delta LIQ_{i,t-1\ to\ t+1} + c^{'}\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \Delta e_{i,t-1\ to\ t+1}$. The second-stage regression model is specified as follows: $INVEFF_{i,t+2} = a + b\Delta\widehat{Channel}_{i,t-1\ to\ t+1} + c^{'}\boldsymbol{\Delta Controls}_{i,t-1\ to\ t+1} + \varepsilon_{i,t+2}$. The channel variable ($\Delta Channel_{i,t-1\ to\ t+1}$) in Panel A is the change in a retained earnings measure surrounding the split-share structure reform, $\Delta RE_{i,t-1\ to\ t+1}$, where the retained earnings measure is computed as the amounts of retained earnings on the balance sheet divided by book total assets at the beginning of the fiscal year. The channel variable in Panel B is the change in an external financing measure surrounding the split-share structure reform, $\Delta EF_{i,t-1\ to\ t+1}$, where the external financing measure is computed as total external financing amounts (i.e., proceeds from getting bank loans and issuing bonds and stocks) divided by book total assets at the beginning of the year. In columns (1) and (2), the model is estimated using the full sample. In columns (3) and (4) (columns (5) and (6)) of all the panels, the model is estimated using the subsample of under-investing firms (over-investing firms), where under-investing firms (over-investing firms) are identified as firms that have a negative (positive) deviation from expected rate of investment in year $t+2$. Δ denotes the change in each variable from the fiscal year before the split-share reform (year $t-1$) to the fiscal year after the split-share reform (year $t+1$), with t indicating the year during which the firm underwent the split-share structure reform. Standard errors are displayed in parentheses below the coefficients. All the remaining variables are defined in Table 1. Superscripts ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

request. First, to further substantiate our tests to overcome endogeneity concerns, we performed an instrumental variable regression using an indicator for split-share structure reform and the lagged average liquidity of all firms in the same industry as instruments for liquidity. We found that our instruments are highly correlated with a firm-level measure of stock liquidity, i.e., *LIQ*. Using the two-stage specifications in Eqs. (3) and (4), we found qualitatively similar results using the instrumented measure of stock liquidity; that is, firms with a greater under-investment propensity invest more with higher stock liquidity, and under-investing firms invest more efficiently when their stocks are more liquid.

Second, to overcome the concern that the Amihud measure might capture trading volume rather than liquidity (Lou and Shu, 2017), following Corwin and Schultz (2012), we used an alternative stock liquidity measure, *LIQ_CS*, which more precisely captures the cost of trading immediacy or the price impact of large trades. Our findings are qualitatively similar to those in Table 3; that is, investment efficiency is positively related to stock liquidity.

Third, to overcome the concern that using *INVEFF* could be flawed—that is, using residuals as dependent variables might bias our regressions (Chen et al., 2018), we estimated a single-stage regression using interactions of the first-stage regressors with year and industry indicators. We also estimated a single-stage regression after including all first-stage regressors in the second stage. Both solutions, as prescribed by Chen et al. (2018), provide similar findings, thus mitigating concerns about using residuals as dependent

variables.

Fourth, we used the turnover ratio as a measure of stock liquidity to overcome the concern that the Amihud measure may not account for stock prices (Brennan and Subrahmanyam, 1996). Even using stock turnover as a measure, our findings are similar to those presented in Table 3.

Finally, we used alternative measures of the investment rate to examine the robustness of our findings. Although these alternative definitions, as defined below, are more inclusive in capturing the different aspects of firms' investment behavior, we relied on a much simpler definition of the investment rate in our baseline tests because these additional components are not reliably available for all listed Chinese firms (Wu et al., 2015). First, we computed the investment rate as the sum of the change in net fixed assets and net acquisition payments (i.e., payments made to acquire subsidiaries/business units minus payments received from the sale of subsidiaries/business units) scaled by lagged total assets. Second, we computed the investment rate as the sum of the change in net fixed assets, net acquisition payments, change in investments classified as construction in progress, and investment properties scaled by lagged total assets. The latter two components measured a firm's real estate investment. Using these two alternative definitions of the investment rate, we repeated all the tests in Table 3 and found qualitatively similar results. Thus, our findings on the relationship between stock liquidity and investment efficiency do not manifest a specific definition of investment rate.

6. Conclusion

This study examines the effect of stock liquidity on investment efficiency with a special focus on the under-investment problem. Based on various studies that provide direct or indirect theoretical arguments that enhanced stock liquidity improves corporate investment efficiency (i.e., reduces under-investment and/or over-investment), we hypothesized that enhanced stock liquidity increases corporate investment efficiency. We exploited the split-share structure reform in China, which provides an exogenous shock to stock liquidity, as a quasi-natural experiment.

We found evidence that enhanced stock liquidity improves the investment of firms that are more prone to under-investment, and thus improves their investment efficiency (i.e., reduces under-investment). We also showed that greater stock liquidity increases investment–Q sensitivity for under-investing firms, suggesting that investment moves toward an optimal level in line with the number of investment opportunities. Using a DiD estimation around the split-share structure reform, we found that the average treatment effect of stock liquidity on investment efficiency is an improvement of 36% in the subsample mean over the pre-split-share reform period. However, we find no positive relationship between stock liquidity and investment efficiency for firms more prone to over-investment.

Our findings were robust to several additional analyses. By investigating the channels through which stock liquidity affects investment efficiency, we found that an increase in stock liquidity is associated with an increase in institutional ownership and information efficiency of stock prices. By employing two-stage regressions, we narrowed down how these mechanisms directly led to different levels of investment efficiency. Specifically, we found that the portion of the increase in institutional ownership and price efficiency explained by liquidity led to an improvement in the investment efficiency of under-investing firms. However, changes in financing constraints, retained earnings, or external financing brought about by liquidity changes cannot account for improvements in investment efficiency. Our findings remain valid when we use a sample of SOEs that are *ex ante* perceived to invest inefficiently. Overall, our findings highlight the positive real effects of stock liquidity on corporate investment behavior and the positive externalities of the Chinese financial market reforms.

Our findings have important practical implications, most notably, in the context of regulation. Although increasing the liquidity of under-investing firms can improve investment decision efficiency, increasing the liquidity of over-investing firms with self-interested managers is ineffective in China. While promoting stock liquidity is helpful in suppressing under-investment problems, liquid stock markets cannot mitigate over-investment problems. Accordingly, we argue that regulators should consider the cross-sectional variations in the impact of stock liquidity on investment efficiency and go beyond *one-size-fits-all* policies. We argue that other forms of policy that improve corporate governance (e.g., promoting independent boards and active institutional ownership) need to complement liquidity policies.

CRediT authorship contribution statement

William Ming Yan Cheung: Conceptualization, Data curation, Software, Writing – original draft, Writing – review & editing. **Hyun Joong Im:** Conceptualization, Data curation, Software, Writing – original draft, Writing – review & editing, Project administration. **Srinivasan Selvam:** Conceptualization, Data curation, Software, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

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Appendix A. Details on the split-share structure reform in China

Following Jiang et al. (2017), we exploited the exogenous shock to stock liquidity from the implementation of the split-share structure reform in China, initiated in 2005, as our key identification technique.[20] Since the establishment of the Shanghai and Shenzhen Stock Exchanges in 1990 as part of China's share issue privatization reforms, a dual split-share structure has been permitted, which allowed for the non-tradability of approximately two-thirds of domestically listed A-shares (Li et al., 2011), across both SOEs and non-SOEs. Holders of such non-tradable shares (NTS) receive similar voting and cash flow rights as holders of tradable shares (TS). Although the split-share structure hastened the pace of privatization by allowing many SOEs to do so, it hampered stock liquidity, weakened corporate governance mechanisms, encouraged speculation, and discouraged active M&A markets (Liao et al., 2014). Therefore, in 2005, the split-share structure reform was initiated to convert all NTS to TS, effectively leading to the second wave of privatization reforms in China. An important feature of the reform was that the holders of the NTS had to negotiate and complete a compensation plan for the holders of TS, who were likely to be adversely affected by the increased supply of tradable shares in the market (Li et al., 2011).[21]

The adoption of the split-share structure reform increased the supply of tradable shares at the firm level and, hence consequently, stock liquidity, while arguably keeping all other observable firm characteristics fixed, because the two classes of shares always had the same voting and cash flow rights (Jiang et al., 2017). Although it is highly probable that split-share structure reform increases stock liquidity, our reliance on reform as a key identification strategy requires that it does not affect other potential confounders associated with corporate investment, such as corporate governance.

To ensure this, we reviewed the literature investigating the effects of split-share structure reforms. Liao et al. (2014) found that although the split-share structure reform helped increase SOEs' productivity and output, it had no effect on corporate governance, such as the frequency of related party transactions, especially among SOEs. Campello et al. (2014) documented similar findings along with an increase in corporate investment and profitability following reforms. Li et al. (2011) investigated the determinants of compensation paid to tradable shareholders and find that a stock's idiosyncratic risk explains most of the compensation. However, they found that the compensation ratio is unaffected by traditional governance proxies such as CEO-chair duality or board characteristics such as size or independence, suggesting that *ex ante* tradable shareholders, when negotiating compensation for the conversion of non-tradable shares, do not factor in the compensation ratio any changes in governance brought about by the conversion. Moreover, Chen et al. (2012) found that the average cash holdings of Chinese firms decreased around the reform period, suggesting that governance improved along with a relaxation in financial constraints.

To minimize the influence of such an effect on our findings, in all our analyses, we controlled for the level of cash holdings and governance proxies, including CEO-chair duality, state ownership, and analyst coverage, to isolate the effect of liquidity on investment efficiency while filtering out the effects of the reform on these governance mechanisms.

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[20] Jiang et al. (2017) documented that the split-share structure reform resulted in a significant and permanent shock to stock liquidity, causing an average increase in liquidity of 35.6% in the post-reform period.

[21] Before making the reform compulsory for all firms, the CSRC chose two sets of pilot firms to assess the reform's impact. After that, the reforms were made mandatory, and firms had to seek the CSRC approval, which was being given in weekly batches. Finally, to implement the reform, each firm sought the approval of the holders of TS for a compensation plan to accommodate the conversion of NTS to TS. Thus, the split-share structure reform was conducted in a staggered manner.

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