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Corporate sustainability policies and corporate investment efficiency: Evidence from the quasi-natural experiment in China

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ABSTRACT

This paper studies the impact of green disclosure on firm investment efficiency, leveraging a policy experiment in China. Since 2012, the Chinese government has begun to implement the Ambient Air Quality Standards (AQS), which have strengthened the requirements for green disclosure throughout the country. We exploit the rollout of the AQS and find that tightening the green disclosure requirements significantly increases corporate investment efficiency. This increase is primarily driven by a reduction in underinvestment among non-state-owned firms and firms with low institutional ownership. Further analysis suggests that the alleviation of agency problems and the reduction of financial constraints are the two main mechanisms through which green disclosure influences firm investment efficiency. Our findings provide valuable policy implications, indicating that strengthening green disclosure standards can have a substantial positive impact on firm investment outcomes.

1. Introduction

As environmental pollution related to energy are of extreme risk (e.g., Gu et al., 2021, 2022; Yan et al., 2022), it has attracted significant attention in China in recent decades (e.g., Zhang et al., 2017; Akpa et al., 2022; Oloko et al., 2022; Ren et al., 2022a, 2022b, 2023; Ho et al., 2023). For instance, according to China's Report on Ecological and Environmental Conditions in 2020, more than 40% of the 337 prefectural-level cities seriously failed to meet air quality standards, resulting in a total of 1152 days of heavy pollution, which have posed immediate and severe risks to public health, infrastructure, and economic/financial stability.[1] Previous research demonstrates the detrimental effects of energy-related environmental pollution on societal health (e.g., Wan et al., 2005a, 2005b), imposing substantial costs on the economy. For instance, Xia et al. (2016) estimated that China experienced a loss of approximately 6.5% of its Gross Domestic Product (GDP) due to health-related issues and decreased productivity caused by heavy pollution during the period of 2000–2010.

To address the environmental pollution linked to energy, China has implemented a range of environment-friendly initiatives. These include programs focused on energy conservation and emission reduction, the adoption of green and low-carbon practices, the enforcement of pollution-reduction requirements, and the promulgation of corporate sustainability policies (Huang et al., 2021; Gu et al., 2021, 2022; Yan et al., 2022). Notably, these initiatives have been effective in reducing pollutant discharges and promoting green investments (Gu et al., 2021; Yan et al., 2022). However, as stressed by several recent studies (Akey and Appel, 2021; Bartram et al., 2022), the compliance costs with environmental regulations can be substantial. A natural question to ask then is whether these environment-friendly initiatives hurt or benefit firm investment efficiency, a key indicator of resource allocation effectiveness and firm growth (e.g., Yan et al., 2022). The answer to this question carries important policy implication, since regulators need to balance the costs and benefits of such initiatives on the society level. If the reduction of pollution comes at the expense of firm investment efficiency, policymakers may need to reconsider the design of these initiatives to minimize the associated costs. On the other hand, if such policies have a positive impact on firm growth (as proxied by measures of investment efficiency), then they can be scaled up to maximize the benefits.

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[1] Out of the days experiencing heavy pollution and above, PM2.5 was identified as the predominant pollutant in 77.7% of cases.

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In this study, we address this question by examining whether the rollout of the Ambient Air Quality Standards (AQS) during 2012–13, a crucial corporate sustainability policy that strengthened firms' green disclosure, affects firm investment efficiency in China. We focus on firm investment efficiency based on the insight that allocating resources effectively is vital to economic growth (Carlin and Mayer, 2003; Levine, 2005). Evaluating corporate investment efficiency provides valuable insights into the effectiveness of resource allocation, making it a crucial metric for assessing the overall health of the real economy (e.g., Gu et al., 2021; Wang et al., 2020; Wen et al., 2022). Following the standard of the energy economics literature (e.g., Yan et al., 2022), we measure corporate investment efficiency in the style of Richardson (2006) as the difference between the actual amount of firm investments and the amount justified by firm fundamentals.

Methodology is of critical importance in empirical research on the energy markets (Narayan, 2015, 2019; Smyth and Narayan, 2015). Using data on Chinese A-share listed firms between 2007 and 2017 and a difference-in-differences (DID) model, where we assign firms into more and less AQS exposed groups based on their pre-determined business attributes, we discover that the AQS policy has increased the investment efficiency of firms with more exposure to the AQS treatment. In particular, our estimates suggest that following the implementation of the policy, investment efficiency jumps by nearly 20% relative to the sample mean for firms more exposed to the AQS policy. Further decomposing the change in investment efficiency, we find that the improvement largely comes from the reduction in firm underinvestment, rather than the decrease in overinvestment.

To further understand the relationship between the AQS and firm investment efficiency, we conduct two sets of literature-guided heterogeneity tests based on firm ownership. State ownership plays an important role in business operations in China. State-owned enterprises (SOEs) often enjoy a more favorable institutional environment relative to their private peers. In particular, when it comes to complying with environmental policies, SOEs often receive protection from local governments, which in turn attenuates the impact of such policies (Gu et al., 2022; Battiston et al., 2021; Wang and Wheeler, 2005). Relating this to our setting, we therefore expect the impact of AQS on firm investment efficiency to be less pronounced for SOEs. This is indeed what we found.

Further, we investigate whether the relationship between AQS implementation and firm investment efficiency varies with institutional ownership. In China, institutional investors often fail to curb firm agency problems. Due to their short-term investment tendencies, institutional investors often lack the willingness to actively participate in corporate governance. As a result, managers in firms with more institutional ownership have more leeway to circumvent compliance with corporate sustainability policies for their own benefits. Thus, we hypothesize and find evidence that the effect of AQS on investment efficiency is less pronounced in firms with higher institutional ownership.

Next, we study the mechanisms that link the implementation of AQS to firm investment efficiency. We argue that the alleviation of agency problems and the reduction of financial constraints, due to a better (green) information environment brought by the AQS, are the two main operating mechanisms. Specifically, we conjecture that the implementation of AQS, through strengthening firm green information disclosure, has improved the information environment for investors. As stressed in recent literature (e.g., Gu et al., 2021), such improvement in the information environment can (a) alleviate agency problems since managers face more scrutiny and (b) facilitate firm access to external finance because financial institutions now face fewer screening and monitoring costs. Indeed, an influential stream of literature shows that agency issues and financial constraints are two major impediments to efficient corporate investments (e.g., Aggarwal and Samwick, 2006; Bertrand and Mullainathan, 2003; John et al., 2008; Narayan et al., 2021, 2023.). Consequently, we expect that the rollout of AQS positively influences firm investment efficiency by addressing these two major hurdles. Following standard practice for causal mechanism tests (e.g., Di Giuli and Laux, 2022), we conducted a causal mediation analysis using the implementation of AQS as an instrument for firm agency problems and financial constraints. The results are consistent with our conjectures.

We further perform a series of robustness tests to provide more confidence in our baseline findings. Reassuringly, our findings remained largely unchanged when we use alternative definitions of the post-event period, include more control variables, perform propensity score matching before rerunning our main analyses, and conduct a large number of placebo tests.

This study makes two key contributions. Firstly, as implied by a growing body of research on the negative effects of energy-related pollution, environmental policies such as the AQS play an important role in reducing air pollution, which in turn mitigates the adverse impact on people's psychological and mental health (Dominici et al., 2006; Chen et al., 2013; Levinson, 2012). However, as the costs of reducing pollutants are typically high, firms may experience lower growth due to compliance with sustainability requirements. This represents a central trade-off faced by policymakers. On one hand, deteriorating environmental conditions due to pollution impose substantial socioeconomic costs. On the other hand, curbing environmental pollution may also hinder firm growth. We address this trade-off in a setting where the government has imposed stricter corporate sustainability requirements (i.e., AQS), and our findings suggest that instead of inhibiting firm growth, the implementation of the AQS increases firm investment efficiency. Therefore, our results inform regulators that protecting the environment and promoting firm growth can be simultaneously achieved through careful policy design.

Our paper also contributes to the literature that investigates the causes of firm investment inefficiency. Previous studies show that firm characteristics, including the quality of corporate governance, relationships with financial institutions, financial reporting activities, and features of their business environment, such as media coverage and institutional quality, shape firm investment efficiency (Chen et al., 2011a; Wang et al., 2020). However, the influence of corporate sustainability policies on firm investment efficiency remains underresearched. An exception is Yan et al. (2022), who study the impact of the establishment of green financial reform and innovation zones in China on firm investment efficiency. Our paper is distinct in the sense that while we examine the effect of AQS, a policy that strengthened green disclosure, Yan et al. (2022) assess a policy that influences the firm's financing environment.

The remainder of the paper is organized as follows. Section 2 develops our main hypotheses. Section 3 outlines our research design, including our data and methodology. In Section 4, we present our main empirical results and investigate the potential mechanisms. Section 6 presents the results from various robustness tests. Section 7 concludes.

2. Hypothesis development

2.1. Mechanisms linking AQS to investment efficiency

We conjecture two main mechanisms linking the implementation of AQS to firm investment efficiency. First, it has been well-established that agency problem is one of the root causes of firm investment inefficiency. Managers' short-termism, which benefits managers themselves at the expense of long-term shareholder value, often leads to underinvestment (e.g., Aggarwal and Samwick, 2006). Furthermore, information asymmetries can exacerbate agency problems, as managers face less monitoring and scrutiny from shareholders and the public, allowing them to prioritize personal interests and under-invest (Bertrand and Mullainathan, 2003). As emphasized by John et al. (2008), instead of focusing on maximizing firm value, managers often exploit company resources to pursue their own benefits and forsake potentially profitable investments

with positive net present value, opting for a conservative approach to avoid personal repercussions that could arise from failed additional investments.

In addition, financing constraint is also a key factor shaping the efficiency of corporate investment. The financing constraint view suggests that the functioning of financial market plays a crucial role in firms' financing decisions (e.g., An et al., 2022; An, 2020; Xu et al., 2023; Cong et al., 2019). When financial markets are not functioning well, firms face substantial costs of raising external capital, which consequently limits their investment (Cong et al., 2019). Information asymmetry is plays a fundamental role in the functioning of financial markets, hence firm access to external finance (e.g., Myers and Majluf, 1984). For instance, Biddle et al. (2009) argue that better information environment mitigates information asymmetry between firms and external investors, reduces adverse selection in the capital market, and thus decreases the cost of capital for financing. Bushman et al. (2011) also suggest that higher-level quality of information disclosure by firms leads to more efficient allocation of capital, enhancing credit allocation efficiency and thus improving investment efficiency. Mandatory disclosure, such as the AQS in our setting, can have positive effect on the information environment, allowing firms to get more access to external (e.g., Dhaliwal et al., 2012; Cheng et al., 2014; Goss and Roberts, 2011). Balakrishnan et al. (2014) also argue that environmental information disclosure can facilitate firm access to external finance.

2.2. Hypotheses

In the face of heightened public scrutiny, highly polluting companies are compelled to confront increased public 'outrage costs,' which prompts them to reduce their emissions. This reduction not only mitigates agency problems but also leads to increased investment in relevant areas, ultimately alleviating underinvestment and enhancing investment efficiency (Gu et al., 2021). Active media scrutiny serves as a powerful external governance mechanism, significantly raising the likelihood of exposing pollution incidents and exerting substantial and sustained public pressure on companies to curtail their emissions. Simultaneously, the market's heightened attention to firms facilitates the discovery of private information and the dissemination of public information. This, in turn, reduces the information asymmetry between firms and investors in the capital market, thereby alleviating financing constraints faced by firms and enhancing their investment efficiency. We thus propose the following hypothesis:

H1. After the implementation of the AQS, the investment efficiency of firms with high environmental risk increases more significantly compared to firms with low environmental risk.

State-owned firms benefit from a more favorable external institutional environment, as they are more likely to receive subsidies and low-cost financing from the government. They also enjoy protection from the local government when it comes to implementing environmental policies, which reduces the pressure on them to comply with rising regulatory costs (Gu et al., 2022; Battiston et al., 2021; Wang and Wheeler, 2005). The government's ownership of state-owned banks gives it control over the allocation of bank credit resources. Consequently, there is a greater allocation of bank credit resources to state-owned enterprises (SOEs), making it challenging for private firms to secure bank financing (Allen et al., 2005). Extensive literature suggests significant 'ownership discrimination' in Chinese bank lending towards private firms (Brandt and Li, 2003; Gordon and Li, 2003). Additionally, addressing the efficiency losses of private equity holding companies due to agency problems has been found to improve investment efficiency more rapidly. As a result, non-state firms are more likely to adjust their investment strategies, allocate more resources to environmental protection, engage in disclosure practices that benefit their development, and foster increased trust among the public and investors. This, in turn, enables them to obtain more financing and create a virtuous circle. To this end, we propose the following hypothesis:

H2. The relationship between AQS and firm investment efficiency is more pronounced in non-state-owned firms than in state-owned firms.

In China's capital market, institutional investors often face difficulties in curbing the agency behavior of firm managers. Due to their short-term investment tendencies, they often lack the willingness to actively participate in corporate governance. As the shareholding of institutional investors increases, the reliability of financial reports from listed companies tends to decrease. According to Porter (1992), the fragmented equity stakes and frequent transactions discourage institutional investors from actively engaging in the governance of investee companies, which can lead to short-sighted behavior by the management. Additionally, effective management oversight requires a value investment philosophy. However, in China, institutional investors tend to be short-term speculators (Jiang and Kim, 2015). Chinese studies indicate that many short-term institutional investors exhibit short-sighted investment behavior. Cao et al. (2020) found that only institutional investors with long-term shareholdings can enhance corporate investment efficiency by mitigating over- and under-investment. Moreover, both the time horizon of institutional investors and the length of their shareholdings were found to have an impact on firm investment efficiency. As a result, we propose the following hypothesis:

H3. The relationship between AQS and firm investment efficiency is more pronounced in firms with less institutional ownership than in firms with more.

3. Data and model

3.1. Measuring investment efficiency

Following the standard of the energy economics literature (e.g., Richardson, 2006; Yan et al., 2022), we calculate firms' inefficient investment levels through model (1):

$$Invest_t = \beta_0 + \beta_1 Growth_{t-1} + \beta_2 Lev_{t-1} + \beta_3 Cashflow_{t-1} + \beta_4 FirmAge_{t-1} + \beta_5 Size_{t-1} + \beta_6 Return_{t-1} + \beta_7 Invest_{t-1} + Industry + Year + \xi_t \quad (1)$$

where, *Invest* represents the level of investment made by the firm during the year. Following the literature (Gu et al., 2021, 2022), we include total asset size (*Size*), firm's year of listing (*FirmAge*), the operating cash flow scaled by total assets (*Cashflow*), firm's growth (*Growth*, i.e., the growth rate of operating revenue), leverage (*Lev*), firm's annual stock return (*Return*), industry fixed effects (*Industry*) and year fixed effects (*Year*) in our model. We focus on the residuals from model (1). Positive residual means overinvested (*Overinv*). Conversely, negative residual represents underinvested (*Underinv*). In our empirical analysis, we utilize the absolute value of the residual to quantify the deviation of the firm's investment from the theoretically expected value. It is important to note that a larger absolute value of the residual corresponds to lower investment efficiency, while a smaller absolute residual value indicates greater firm investment efficiency.

Following the standard of the literature (e.g., Biddle et al., 2009; Chen et al., 2011b; Kim et al., 2021), we construct two alternative measures of investment inefficiency using models (2) and (3) as follows:

$$Invest_t = \beta_0 + \beta_1 Growth_{t-1} + \xi_t \quad (2)$$

$$Invest_t = \beta_0 + \beta_1 Growth_{t-1} + \beta_2 NEG_{t-1} + \beta_3 Growth_{t-1} \times NEG_{t-1} + \xi_t \quad (3)$$

where *NEG* is a dummy variable that equals to 1 if Growth is below zero, and 0 otherwise. The definition of *Growth* is the same as the model (1). The firm's inefficient investment level is measured by the absolute value of the residual after controlling for year and industry fixed effects.

3.2. Models

We use the following generalized difference-in-difference (DID) model, to study how the new ambient air quality standards, the AQS, affects the efficiency of corporate investment:

$$Absinv_t = \beta_0 + \beta_1 Post_t \times Treat_t + \beta_2 Post_t + \beta_3 Treat_t + \beta_i controls_t + Firm + Year + \varepsilon_t \quad (4)$$

where *Post* is a dummy variable that equals to 1 for time after the implementation of the AQS and 0 otherwise. We define here the implementation date as the end of October 2013 when 116 cities, mostly model cities, were connected to the China General Environmental Monitoring Station and started to report real-time data on key pollutants. As a result, years starting 2014 are assigned a value of 1 in *Post.* The specific regions and corresponding policy years are shown in Fig. 1. *Treat* represents the extent to which firms face environmental risks. We asign listed companies in heavily polluting industries (16 industries in total) to high environmental risk group, and, correspondingly, *Treat* equals to 1 for this group. We assign a value of 0 to firms that belong to other sectors. Our variable of interest is the interaction between *Post* and *Treat.* As *Absinv* proxies for investment inefficiency, we expect $\beta 1$ to be negative. We control for firm and year fixed effects in the model. According to the existing literature (Gu et al., 2021, 2022), we also control for firm size (*Size*), leverage (*Lev*), return on assets (*ROA*), operating net cash flow (*Cashflow*), years of listing (*FirmAge*), board size (*Board*), number of independent directors (*Indep*), CEO-Chairman duality (*Dual*), the largest shareholder's ownership (*Top1*), as well as management's ownership (*Mshare*). We define these variables in Table 1.

3.3. Sample and data

We first obtain data on A-share listed firms during 2007–2017 from China Stock Market & Accounting Research Database (CSMAR) China A-share listed companies from 2007 to 2017. Following the literature (Yan et al., 2022), we then select our sample in the following ways: (1) focus on firms from the non-financial sector; (2) remove firms labeled as ST or *ST companies as they are about to be delisted; and (3) remove companies with insufficient information (missing values) for our analysis. In total, we have 17,054 observations. We winsorzie the data at the 1% and 99% levels to account for the influence of outliers.

Table 1
Definition of variables.

Variables	Definition
Absinv	The absolute value of residuals from the model (1)
Absinv2	The absolute value of residuals from the model (2)
Absinv3	The absolute value of residuals from the model (3)
Post	Equal to 1 for policy years and after and 0 otherwise
Treat	Equal to 1 for firms in high environmental risk industries and 0 otherwise
Size	Natural logarithm of the company's total assets at the end of the year
Lev	Total liabilities/total assets at the end of the year
ROA	Net profit/total assets at the end of the year
Cashflow	Net cash flow from operating activities/total assets at the end of the year
FirmAge	ln (current year-year of incorporation+1)
Board	Natural logarithm of the total number of board members
Indep	Percentage of independent directors on the board
Dual	Equal to 1 if the chairman is also CEO and 0 otherwise
Top1	Ownership of the largest shareholder at the end of the year
Mshare	Share of management ownership at the end of the year

Note: This table presents the definitions for all variables.

3.4. Descriptive statistics

The descriptive statistics are shown in Table 2. According to Table 2, the mean of our key measure of investment inefficiency *Absinv* is 0.05, with a standard deviation of 0.11. As suggested by these statistics, there is a significant amount of variations in the efficiency of firm investment

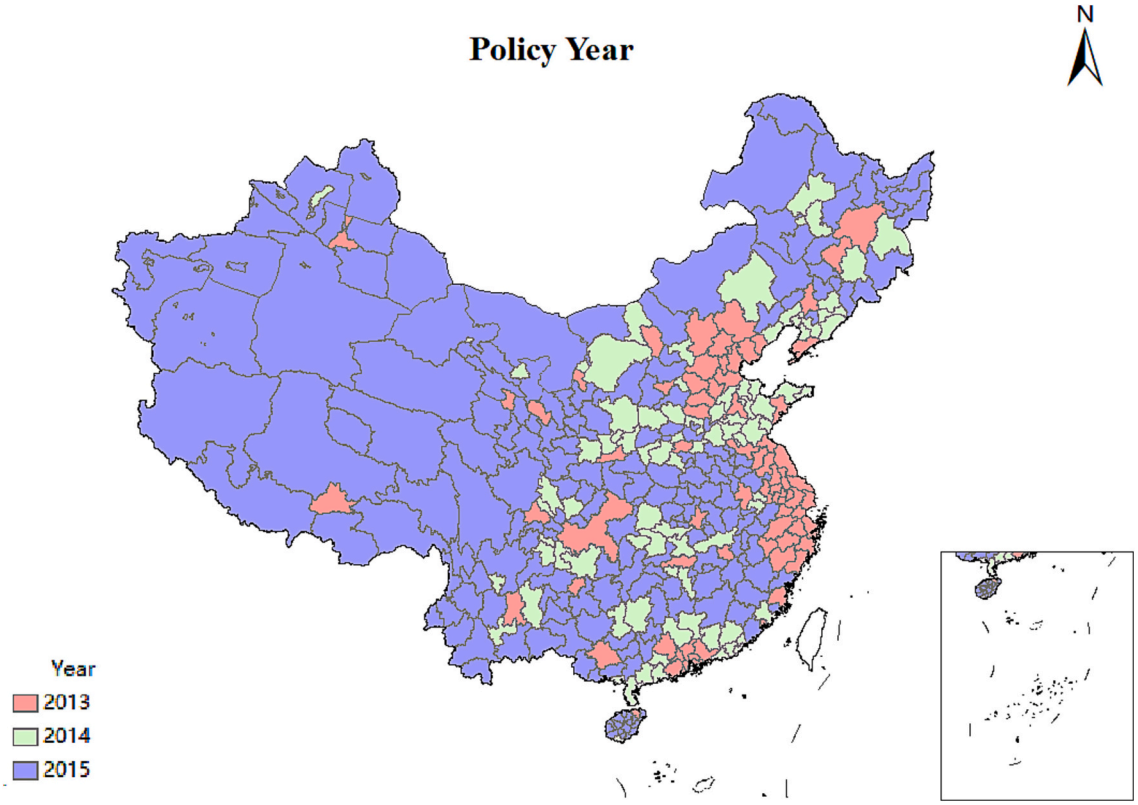

Fig. 1. Policy region and corresponding year.

Table 2
Summary statistics.

Variables	N	Mean	Median	Min	Max	SD
Absinv	17,054	0.0500	0.0300	0	7.108	0.110
Size	17,054	22.14	21.97	19.35	26.11	1.249
Lev	17,054	0.455	0.457	0.0270	0.925	0.205
ROA	17,054	0.0420	0.0360	−0.205	0.245	0.0540
Cashflow	17,054	0.0460	0.0450	−0.224	0.283	0.0720
Growth	17,054	0.200	0.119	−0.651	4.806	0.483
Board	17,054	2.162	2.197	1.609	2.708	0.199
Indep	17,054	0.371	0.333	0.250	0.600	0.0520
Dual	17,054	0.211	0	0	1	0.408
BM	17,054	0.959	0.637	0.0510	7.108	0.956
FirmAge	17,054	2.755	2.773	1.099	3.497	0.345
Top1	17,054	0.353	0.335	0.0840	0.758	0.150
Mshare	17,054	0.0920	0	0	0.709	0.172

Notes: This table reports descriptive statistics (namely, observations (N), mean, maximum (Max), minimum (Min), median, and standard deviation (SD)). The sample contains 17,054 firm-year observations over the period 2007–2017. See Table 1 for variable definitions.

in our sample. The summary statistics of control variables are generally consistent with the literature (e.g., Gu et al., 2021, 2022).

4. Empirical results

In this section, we present the results from our main estimations, heterogeneity analyses, and our channel tests.

4.1. Baseline regressions

The regression results of Model (4) are reported in Table 3. The impact of ambient air quality information disclosure, the AQS, on firm investment efficiency is demonstrated in Column (1), with an estimated coefficient of −0.01007 on the interaction term *Post* × *Treat*. The coefficient is significant at the 1% level, with a t-value of −2.70, and is equivalent to 9.15% of the standard deviation of *Absinv* in the sample. Column (2) and (3) report the results of the regressions that separately test the impact of the AQS on firm over-investment and under-investment. In Column (2), the coefficient on *Post* × *Treat* is −0.00717, which is statistically insignificant. In Column (3), the estimated coefficient on *Post* × *Treat* is −0.00589. The coefficient is significant at the 5% level, with a t-value of −2.18, which is generally consistent with our first hypothesis. This result here shows that the disclosure of ambient air quality information significantly affects the efficiency of business investment and mainly reduces underinvestment by firms.

4.2. The role of state and institutional ownership

We categorized the companies in our sample into two groups: state-owned firms (SOE = 1) and non-state-owned firms (SOE = 0), based on their ownership status. The results of the group regressions are presented in Table 4. In column (1), the coefficient of the cross-product term *Post* × *Treat* is −0.00692, which is statistically significant at the 10% level. In column (2), the corresponding coefficient is −0.01372 and is significant at the 5% level. This difference suggests that the new AQS has a stronger positive impact on enhancing the investment efficiency of non-state-owned firms with high environmental risk, which aligns with hypothesis H2.

Furthermore, we divided the companies in our sample into two groups based on the relative level of their institutional investor

Table 3
Results of the baseline regressions.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.01007***	−0.00717	−0.00589**
	(−2.70)	(−1.07)	(−2.18)
Size	0.02751***	0.06197***	−0.00564**
	(2.70)	(2.92)	(−2.50)
Lev	0.02727	0.10349**	0.00163
	(0.99)	(2.02)	(0.18)
ROA	0.10321***	0.10735	0.12895***
	(2.60)	(1.15)	(5.85)
Cashflow	−0.05139***	−0.03872	−0.04081***
	(−3.21)	(−0.94)	(−3.77)
Growth	0.02739***	0.05324***	0.00312*
	(4.41)	(4.34)	(1.71)
Board	−0.00815	−0.01846	0.00920
	(−0.95)	(−0.92)	(1.14)
Indep	−0.01577	0.00351	0.01904
	(−0.54)	(0.06)	(0.84)
Dual	−0.00462	−0.02048	0.00102
	(−1.09)	(−1.40)	(0.41)
BM	−0.00690**	−0.01102	−0.00078
	(−2.56)	(−1.49)	(−0.81)
FirmAge	−0.02415	0.01625	−0.02160*
	(−1.49)	(0.30)	(−1.85)
Top1	0.01699	0.04945	−0.01012
	(0.45)	(0.56)	(−0.83)
Mshare	−0.02011	−0.04664	−0.00927
	(−0.55)	(−0.35)	(−0.74)
Observations	16,845	6443	9861
R-squared	0.244	0.478	0.356
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.123	0.287	0.179

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Table 4
Heterogeneity tests.

	(1)	(2)	(3)	(4)
Variables	SOE = 1	SOE = 0	Ishold = 1	Ishold = 0
Post×Treat	−0.00692*	−0.01372**	−0.00259	−0.01284***
	(−1.89)	(−1.96)	(−0.46)	(−2.89)
Size	0.00781	0.04074**	0.03152*	0.02183**
	(1.26)	(2.16)	(1.81)	(2.21)
Lev	−0.01838	0.07043*	0.04317	0.01786
	(−0.87)	(1.71)	(1.18)	(0.67)
ROA	0.09177***	0.06470	0.07514	0.11405***
	(2.94)	(0.83)	(0.99)	(2.81)
Cashflow	−0.04039***	−0.04355	−0.06205**	−0.04697**
	(−3.27)	(−1.52)	(−2.02)	(−2.53)
Growth	0.00915*	0.03718***	0.02057***	0.02410***
	(1.85)	(3.83)	(2.88)	(2.72)
Board	−0.01646	−0.00808	0.02379*	−0.03621**
	(−1.37)	(−0.61)	(1.77)	(−2.39)
Indep	0.01697	−0.04787	0.05007	−0.10613**
	(0.40)	(−1.12)	(0.81)	(−2.38)
Dual	−0.00349	−0.00692	−0.00013	−0.00262
	(−1.31)	(−1.06)	(−0.03)	(−0.63)
BM	−0.00441***	−0.00444	−0.00886***	−0.00241
	(−3.55)	(−0.59)	(−3.29)	(−0.56)
FirmAge	−0.00066	−0.03794	−0.01302	−0.06136**
	(−0.04)	(−1.60)	(−0.62)	(−2.53)
Top1	0.00357	0.04572	0.00055	−0.05723*
	(0.13)	(0.65)	(0.01)	(−1.83)
Mshare	0.05842	−0.02095	0.00088	−0.00665
	(0.43)	(−0.55)	(0.02)	(−0.42)
Observations	7998	8772	8278	8244
R-squared	0.210	0.296	0.368	0.430
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm
Adj. R-squared	0.0988	0.158	0.233	0.302

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

shareholding ratio compared to the industry median for the same year. Specifically, the low institutional investor shareholding group (Inshold = 0) comprises firms with a shareholding ratio lower than the industry median for that year. The results exhibit more prominent patterns within the low institutional investor shareholding group, as evidenced by columns (3) and (4) in Table 4, supporting hypothesis H3.

4.3. Mechanism analysis

Based on theoretical analysis (Huang et al., 2021), the disclosure of ambient air quality information indirectly stimulates firms to enhance their production methods, encompassing energy conservation, emission reduction, green and low-carbon practices, and stricter control of pollutant emissions. This instigates shareholders to prioritize corporate governance, resulting in increased investment related to corporate activities and necessitating prudent utilization of corporate financing. To evaluate the corporate agency problem, we utilize the management expense ratio, proposed by Ang et al. (2000), where a lower ratio indicates a reduced agency problem. Furthermore, we consider overhead costs as a mediating mechanism through which the disclosure of ambient air quality information influences the efficiency of firm investment.

Building upon the conceptual framework introduced by Kaplan and Zingales (1997), we have developed the KZ index to investigate the mediating mechanism through which the disclosure of environmental air information influences corporate investment efficiency. By implementing policies that mandate the disclosure of ambient air quality information and establishing national key cities and model cities for environmental protection, there has been a significant enhancement in the transparency of such information. As a result, the information asymmetry between the central government and local governments has been substantially reduced (Greenstone et al., 2021). This has motivated high environmental risk firms to prioritize pollution emissions control and environmental protection, thereby strengthening their commitment to social responsibility and reaping greater benefits. Consequently, these actions lead to a reduction in the cost of equity financing, improved access to commercial credit financing, and a mitigation of the financing constraints faced by firms. Simultaneously, efforts to address the mismatch between financing sources and maturity stimulate firms to amplify their investments in research and development related to green innovation. This, in turn, fuels the pursuit of green innovation activities, establishing a virtuous circle of progress.

In this study, we exercise caution in utilizing methods that validate mediating mechanisms, as they are more suitable for psychological research and less applicable to economic analysis. These methods are susceptible to endogeneity problems. Instead, we adopt the approach introduced by Di Giuli and Laux (2022), which employs causal mediation analysis within the framework of instrumental variables regression. This methodology provides a more robust and reliable means of examining mediation effects. Specifically, we employ the *Post* × *Treat* variable as the instrumental variable, which enables us to effectively analyze the mediating role of the identified variables.

Our primary objective is to examine whether the disclosure of ambient air quality information influences firm investment efficiency through the intermediary factors of agency problems and financing constraints. Furthermore, we aim to investigate the two stages of this causal pathway using an instrumental variables approach. By employing the *Post* × *Treat* indicator variable as the instrumental variable, we can assess the impact of the instrumental variable on agency problems and financing constraints through first-stage regressions, and subsequently, the impact of agency problems and financing constraints on firm investment efficiency through second-stage regressions.

Based on our hypotheses, we anticipate a significant negative relationship between the disclosure of environmental air quality information and both agency problems and financing constraints. Additionally, we expect agency problems and financing constraints to have a strong association with firm investment efficiency. The findings presented in Table 3, which establish a link between the disclosure of environmental information and investment efficiency, provide supporting evidence for the connection between environmental information disclosure and these intermediary factors, as well as their relationship with firm investment efficiency. However, if we observe limited significant relationships between the disclosure of environmental air quality information and agency problems/financing constraints, or if these relationships deviate from our expectations, it suggests the presence of alternative pathways, beyond agency problems and financing constraints, to explain our scenarios. To test our hypotheses, we employ the following equation:

$$KZ_t = \beta_0 + \beta_1 post_t \times treat_t + \beta_2 Controlvariables + Fixedeffects + \epsilon_1 \quad (5)$$

$$Absinv_t = \beta_0 + \beta_1 KZ_t + \beta_2 Controlvariables + Fixedeffects + \epsilon_2 \quad (6)$$

$$Mfee_t = \beta_0 + \beta_1 post_t \times treat_t + \beta_2 Controlvariables + Fixedeffects + \epsilon_1 \quad (7)$$

$$Absinv_t = \beta_0 + \beta_1 Mfee_t + \beta_2 Controlvariables + Fixedeffects + \epsilon_2 \quad (8)$$

The corresponding results are presented in Table 5. In Column (1), the findings demonstrate that the disclosure of ambient air quality information has a significant alleviating effect on firms' financing constraints at the 1% statistical level. Column (2) reveals that the presence or intensification of financing constraints significantly impairs firms' investment efficiency. In Column (3), the estimation reveals the impact of environmental air quality information disclosure on firms' agency problems, indicating a noteworthy reduction in agency problems.

Table 5
Testing intermediary mechanisms.

	(1)	(2)	(3)	(4)
Variables	KZ	Absinv	Mfee	Absinv
Post×Treat	−0.13904***		−0.00162**	
	(−2.91)		(−2.16)	
KZ		0.06773*		
		(1.92)		
Mfee				6.23128*
				(1.65)
Size	−0.83148***	0.08503***	−0.01311***	0.10923**
	(−20.38)	(2.65)	(−17.20)	(2.14)
Lev	5.82427***	−0.36585*	0.00665***	−0.01418
	(37.05)	(−1.75)	(2.78)	(−0.35)
ROA	−4.69901***	0.42328**	−0.01819***	0.21653**
	(−14.00)	(2.46)	(−3.40)	(2.52)
Cashflow	−13.03738***	0.84075*	0.01936***	−0.17202**
	(−77.34)	(1.82)	(8.59)	(−2.35)
Growth	−0.06206**	0.02899***	0.00134***	0.01907**
	(−2.19)	(3.99)	(3.94)	(2.36)
Board	−0.00637	−0.00874	0.00584***	−0.04453
	(−0.05)	(−0.69)	(3.00)	(−1.64)
Indep	0.27972	−0.01437	0.00516	−0.04790
	(0.84)	(−0.37)	(1.01)	(−0.97)
Dual	−0.03106	−0.00190	0.00006	−0.00498
	(−0.81)	(−0.34)	(0.09)	(−0.86)
BM	0.02795	−0.00836**	−0.00174***	0.00394
	(1.30)	(−2.51)	(−5.12)	(0.56)
FirmAge	1.35749***	−0.11338**	0.01107***	−0.09312*
	(6.17)	(−2.12)	(3.30)	(−1.86)
Top1	0.15985	0.01054	−0.00555	0.05156
	(0.70)	(0.23)	(−1.38)	(1.07)
Mshare	−0.75425***	0.03260	−0.00330	0.00044
	(−3.33)	(0.57)	(−0.71)	(0.01)
Observations	16,387	16,387	16,845	16,845
R-squared	0.831	−0.515	0.857	−0.511
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm
Adj. R-squared	0.803	−0.518	0.834	−0.513

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Furthermore, Column (4) indicates that as agency problems decrease, firms' investment efficiency significantly improves. These results support our hypothesis and provide compelling evidence for the existence of two influential channels: financing constraints and agency problems.

5. Robustness checks

5.1. Placebo tests

Following, La Ferrara et al. (2012), Li et al. (2016), and Guo and An (2022), We first perform a placebo exercise where we randomly assign firms into treated and control groups and re-do our main analysis. We repeat this exercise for 1000 times and plot the coefficients on the interaction term in Fig. 2. We also super-impose the estimate from our baseline analysis in the figure. As shown in Fig. 2, our true estimate lies far from the center of the distribution, indicating that our results are unlikely spurious.

5.2. Alternative measures of Core variables

In addition to the Richardson (2006) calculation of investment efficiency used in the previous sections, we constructed two alternative investment efficiency indicators, *Absinv2* and *Absinv3*, following the method of Biddle et al. (2009) and Chen et al. (2011a). Similar to the main indicator, smaller absolute values of these measures indicate better investment efficiency. The results are shown in Table 6, where the DID estimates are statistically significant and negative, suggesting that our results in Table 4 are not sensitive to the particular measures of investment efficiency.

5.3. Controlling the possible impact of exogenous events

Considering the events that occurred within our sample period, e.g., the 2008 international financial crisis, the Beijing Olympics, and the APEC Summit, may have confounded the results of this paper. We perform a set of analyses where we exclude observations from 2008

Table 6
Alternative measures of core variables.

	(1)	(2)
Variables	Absinv2	Absinv3
Post×Treat	−0.00285*	−0.00267*
	(−1.92)	(−1.79)
Size	0.00265**	0.00210*
	(2.45)	(1.92)
Lev	0.02060***	0.01994***
	(4.82)	(4.61)
ROA	0.03244***	0.02863***
	(3.60)	(3.17)
Cashflow	0.00073	0.00058
	(0.17)	(0.13)
Growth	0.00225***	0.00257***
	(2.68)	(3.06)
Board	−0.00553*	−0.00514
	(−1.68)	(−1.56)
Indep	−0.01110	−0.01020
	(−1.09)	(−0.99)
Dual	0.00078	0.00102
	(0.67)	(0.87)
BM	−0.00433***	−0.00435***
	(−6.15)	(−6.16)
FirmAge	−0.01796***	−0.01744**
	(−2.64)	(−2.54)
Top1	−0.00039	−0.00003
	(−0.06)	(−0.00)
Mshare	−0.00247	−0.00224
	(−0.39)	(−0.35)
Observations	16,825	16,825
R-squared	0.301	0.305
Firm FE	YES	YES
Year FE	YES	YES
Cluster	Firm	Firm
Adj. R-squared	0.189	0.194

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

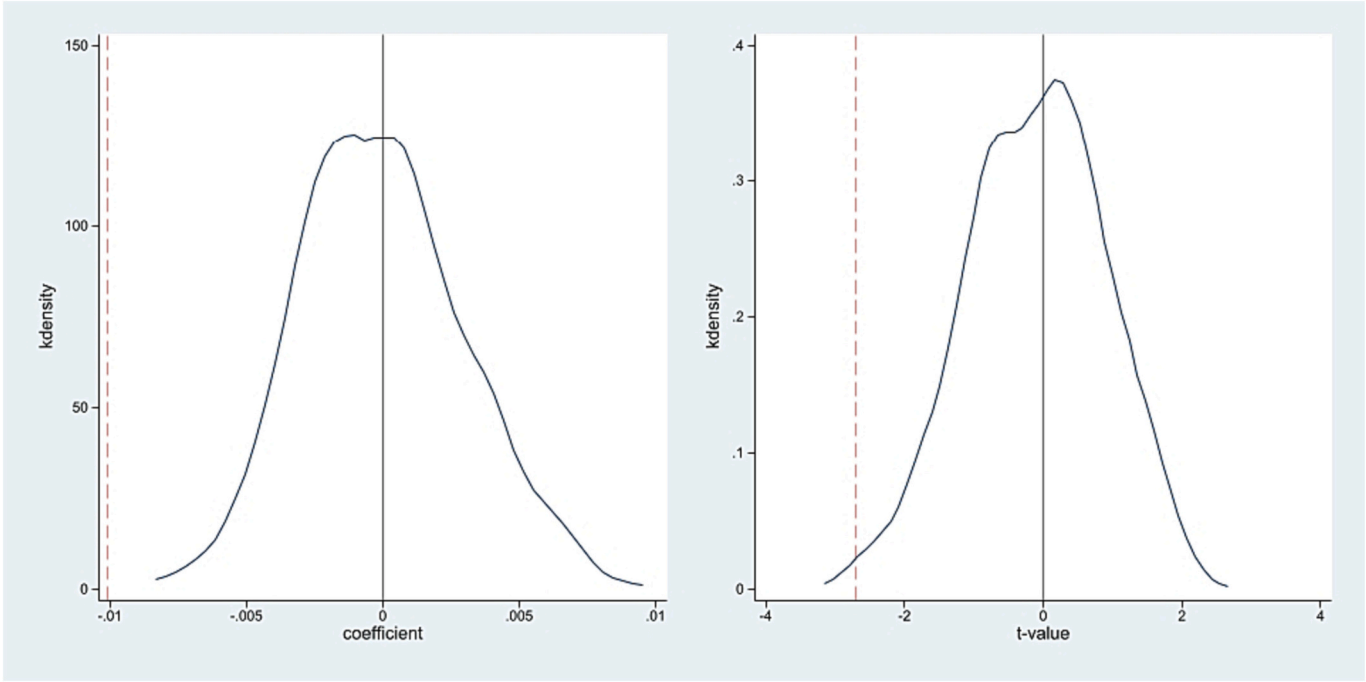

Fig. 2. Results from the Placebo test.

Table 7
Control the possible impact of exogenous events.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.01063***	−0.00435	−0.00632**
	(−2.71)	(−0.55)	(−2.13)
Size	0.02900**	0.07246***	−0.00761***
	(2.58)	(2.77)	(−2.75)
Lev	0.02565	0.12459**	0.00563
	(0.83)	(1.99)	(0.56)
ROA	0.10714**	0.09584	0.14989***
	(2.49)	(0.82)	(6.03)
Cashflow	−0.05243***	−0.03648	−0.04555***
	(−2.73)	(−0.72)	(−3.78)
Growth	0.03013***	0.05650***	0.00324*
	(4.48)	(4.11)	(1.71)
Board	−0.01123	−0.02628	0.00806
	(−1.17)	(−1.17)	(0.94)
Indep	−0.01680	0.02410	0.02662
	(−0.51)	(0.35)	(1.02)
Dual	−0.00697	−0.02823	0.00240
	(−1.35)	(−1.57)	(0.83)
BM	−0.00684**	−0.01142	−0.00025
	(−2.54)	(−1.31)	(−0.24)
FirmAge	−0.02349	0.00215	−0.01642
	(−1.30)	(0.04)	(−1.37)
Top1	0.03487	0.08249	−0.00515
	(0.70)	(0.78)	(−0.36)
Mshare	−0.03763	−0.06405	−0.01325
	(−0.81)	(−0.40)	(−0.88)
Observations	13,959	5227	8027
R-squared	0.271	0.492	0.417
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.127	0.273	0.209

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Table 8
Adjustment of policy settings.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.00773*	−0.00775	−0.00586**
	(−1.79)	(−1.24)	(−2.37)
Size	0.02752***	0.06186***	−0.00571**
	(2.70)	(2.91)	(−2.53)
Lev	0.02732	0.10292**	0.00162
	(1.00)	(2.00)	(0.18)
ROA	0.10300***	0.10689	0.12912***
	(2.60)	(1.14)	(5.86)
Cashflow	−0.05142***	−0.03877	−0.04070***
	(−3.21)	(−0.94)	(−3.76)
Growth	0.02740***	0.05322***	0.00314*
	(4.41)	(4.34)	(1.72)
Board	−0.00794	−0.01829	0.00925
	(−0.92)	(−0.92)	(1.15)
Indep	−0.01605	0.00373	0.01860
	(−0.55)	(0.06)	(0.82)
Dual	−0.00466	−0.02050	0.00100
	(−1.10)	(−1.41)	(0.41)
BM	−0.00692**	−0.01096	−0.00076
	(−2.57)	(−1.49)	(−0.79)
FirmAge	−0.02419	0.01649	−0.02150*
	(−1.49)	(0.30)	(−1.84)
Top1	0.01695	0.04977	−0.01007
	(0.45)	(0.57)	(−0.82)
Mshare	−0.02000	−0.04608	−0.00914
	(−0.54)	(−0.34)	(−0.73)
Observations	16,845	6443	9861
R-squared	0.244	0.478	0.356
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.123	0.287	0.179

Noted: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

(which included the global financial crisis and the Beijing Olympics) and 2014 (the APEC Summit in Beijing). The test results are presented in Table 7. The new estimation results remain significant, and the study's findings are consistent with Table 4.

5.4. Adjustment of policy settings

According to the Implementation Plan for the Third Phase Monitoring of the New Air Quality Standards, real-time air quality monitoring results were made available in 2015 for cities at the prefecture-level and above nationwide. Therefore, 2015 serves as the designated cut-off year for determining the assignment of the post in such cases. However, in our entire sample, we encountered a lack of corresponding control group data for the final period when the multi-period Difference-in-Differences (DID) analysis was implemented. This discrepancy has led to conflicting opinions in prior studies. To ensure the integrity of our study, we opted to maintain 2015 as the third period of policy implementation and conducted our analysis based on this framework. The regression results derived from this approach are presented in Table 8, affirming the validity of our conclusions.

5.5. Additional control variables

To avoid biased estimation due to possible missing control variables, we also added the ratio of corporate R&D investment to revenue (*RD*), the natural logarithm of GDP per capita of firm location (*lnGDP*) and the stock return (*Return*). As shown in Table 9, the new results remain robust after the addition of these control variables.

5.6. The PSM-DID estimations

Although the Difference-in-Differences (DID) method provides a solution to the endogeneity problem, it does not fully address the challenges arising from sample selection bias. Conversely, the propensity score matching method is more effective in controlling the influence of individual differences on study results. As a result, we employ a combination of both approaches to mitigate estimation bias in the DID model and address the issue of sample selection bias before conducting the regression analysis.

Based on the results presented in Columns (1) and (3) of Table 10 from the basic regression using the propensity score matching method, both the inefficient investment levels and underinvestment scenarios exhibit similar effects. The estimated coefficients of *Post* × *Treat* are −0.01008 and − 0.00563, respectively, and both are significantly negative at the 1% and 5% statistical levels. These findings provide further support for the hypotheses proposed in this paper.

5.7. Parallel trend test

One of the fundamental assumptions of the Difference-in-Differences (DID) model is the parallel trend assumption. This assumption states that differences between the control and treatment groups should only emerge after the implementation of the new air quality standards. Prior to this implementation, companies in areas where the new standards have not been applied should exhibit a consistent trend of change in the Non-compliance Environmental Investment (NCEI) comparable to companies in areas where the new standards have been implemented.

We examine the hypothesis of parallel trends within the sample. To do so, this study introduces five yearly dummy variables: Pre_2, Pre_1,

Table 9
Additional control variables.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.00946**	−0.00449	−0.00630**
	(−2.55)	(−0.69)	(−2.28)
Size	0.02786***	0.06434***	−0.00661***
	(2.62)	(2.93)	(−2.80)
Lev	0.04088	0.10461*	0.01036
	(1.49)	(1.94)	(1.09)
ROA	0.11124***	0.09068	0.14604***
	(2.65)	(0.93)	(6.25)
Cashflow	−0.05073***	−0.04963	−0.03780***
	(−3.15)	(−1.18)	(−3.35)
Growth	0.02528***	0.05289***	0.00339*
	(4.11)	(4.14)	(1.80)
Board	−0.00858	−0.01288	0.00859
	(−0.96)	(−0.63)	(1.03)
Indep	−0.01659	0.01838	0.01560
	(−0.55)	(0.29)	(0.66)
Dual	−0.00551	−0.02232	0.00089
	(−1.23)	(−1.47)	(0.35)
BM	−0.00771***	−0.01056	−0.00258**
	(−2.73)	(−1.38)	(−2.43)
FirmAge	−0.01898	0.02158	−0.02050*
	(−1.18)	(0.39)	(−1.71)
Top1	0.01759	0.05895	−0.00806
	(0.44)	(0.64)	(−0.64)
Mshare	−0.01939	−0.06081	−0.00766
	(−0.50)	(−0.42)	(−0.59)
RD	−0.00042	−0.00115	0.00033
	(−0.67)	(−0.91)	(1.13)
lnGDP	0.00014	0.00319	0.00226
	(0.03)	(0.27)	(0.56)
Return	−0.00206	0.00240	−0.00793***
	(−1.33)	(0.74)	(−6.46)
Observations	16,032	6118	9388
R-squared	0.249	0.482	0.357
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.128	0.289	0.180

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Current, Post_1, and Post_2. These variables represent the two years preceding the implementation of the new Air Quality Standards (AQS) and the three years following their implementation. We substitute the

Table 11
Results from the PSM-DID method.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.01008***	−0.00763	−0.00563**
	(−2.68)	(−1.13)	(−2.07)
Size	0.02757***	0.06239***	−0.00567**
	(2.70)	(2.92)	(−2.51)
Lev	0.02752	0.10460**	0.00194
	(1.00)	(2.04)	(0.22)
ROA	0.10295***	0.10801	0.12948***
	(2.58)	(1.14)	(5.86)
Cashflow	−0.05253***	−0.04078	−0.04149***
	(−3.27)	(−0.99)	(−3.83)
Growth	0.02741***	0.05328***	0.00312*
	(4.41)	(4.34)	(1.71)
Board	−0.00819	−0.01783	0.00897
	(−0.95)	(−0.89)	(1.11)
Indep	−0.01549	0.00473	0.01906
	(−0.53)	(0.08)	(0.84)
Dual	−0.00463	−0.02041	0.00096
	(−1.09)	(−1.40)	(0.39)
BM	−0.00705**	−0.01139	−0.00082
	(−2.54)	(−1.48)	(−0.83)
FirmAge	−0.02369	0.01613	−0.02139*
	(−1.46)	(0.29)	(−1.83)
Top1	0.01701	0.04884	−0.01004
	(0.45)	(0.56)	(−0.82)
Mshare	−0.01996	−0.04623	−0.00925
	(−0.54)	(−0.35)	(−0.74)
Observations	16,803	6423	9838
R-squared	0.244	0.478	0.356
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.123	0.287	0.179

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Table 10
Results from the PSM balance test.

Variables	Type	Mean		Standardized Bias %	Standardized Bias Change %	T	P > | t |
		Treat	Control				
Size	Before	22.237	22.094	11.3	90.7	6.0.96	0.000
	After	22.219	22.206	1.1		0.54	0.588
Lev	Before	0.45919	0.45313	3.0	83.4	1.80	0.071
	After	0.45735	0.45634	0.5		0.26	0.798
ROA	Before	0.04041	0.04221	−3.2	71.9	−2.02	0.043
	After	0.04068	0.04118	−0.9		−0.46	0.642
Cashflow	Before	0.05677	0.04058	22.9	97.8	13.72	0.000
	After	0.05634	0.0567	−0.5		−0.27	0.791
Growth	Before	0.1716	0.21273	−8.8	98.0	−5.20	0.000
	After	0.17247	0.1733	−0.2		−0.10	0.921
Board	Before	2.1887	2.149	20.0	97.9	12.22	0.000
	After	2.1861	2.1869	−0.4		−0.22	0.823
Indep	Before	0.36635	0.37263	−12.2	99.7	−7.33	0.000
	After	0.3665	0.36648	0.0		0.02	0.984
Dual	Before	0.18697	0.22247	−8.8	98.2	−5.31	0.000
	After	0.1879	0.18853	−0.2		−0.08	0.933
BM	Before	1.05	0.91552	13.7	94.5	8.59	0.000
	After	1.0245	1.0171	0.8		0.38	0.701
FirmAge	Before	2.7516	2.7573	−1.7	78.8	−1.01	0.311
	After	2.7509	2.7497	0.4		0.19	0.853
Top1	Before	0.36092	0.34895	8.0	94.5	4.88	0.000
	After	0.36	0.35934	0.4		0.23	0.819
Mshare	Before	0.07546	0.09955	−14.3	98.2	−8.55	0.000
	After	0.07605	0.07561	0.3		0.14	0.885

Post × Treat term in Eq. (4) with the product of these dummy variables and conduct the regression analysis accordingly. The results are presented in Table 11. Initially, the coefficients of *Pre_2* × *Treat* and *Pre_1* × *Treat* are found to be statistically insignificant, aligning with the parallel trend hypothesis. Moreover, based on the magnitude and significance of the coefficients for *Current* × *Treat* and *Post_1* × *Treat*, it is evident that there are substantial differences in investment efficiency between the control and treatment groups during the year of AQS implementation and the subsequent year. These findings suggest that the experimental and control group samples used in this paper conform to the parallel trend hypothesis of the model, and the policy effects may exhibit short-term characteristics. (See Table 12.)

5.8. Controlling for the impact of other policies

We are also concerned about the potential impact of other concurrent government policies on our results. For example, China implemented pilot emission permits in some provinces in 2007 and established pilot green financial systems in a selection of provinces during 2015–2017 (e.g., Yan et al., 2022). If these sustainability policies influenced firm investment efficiency in either direction, then what we are capturing here may simply reflect the effects of other government policies. To address this concern, we leverage a unique feature of our empirical design, where the treatment in our study is at the city level. This allows us to include province-by-year fixed effects to account for the impact of those aforementioned provincial-level policies. We present our results in Table 13, which show that our findings remain largely unchanged even when considering these important policies.

5.9. Further analysis

We segmented the policy implementation areas into three distinct regional categories: Western, Central, and Eastern China. This division allowed us to investigate how the implementation of the policy impacts the investment efficiency of firms in each region. The corresponding estimation results are outlined in Table 14. The findings reveal a significant improvement in investment efficiency for firms located in the eastern region. However, no significant improvement in investment efficiency was observed for firms in the central and western regions.

There could be several reasons for these findings. Firstly, it is important to consider the geographical distribution of Chinese firms, as a majority of them are located in the eastern region. Due to this concentration, there may be a quantitative bias in the results, with fewer firms being represented in the central and western regions. Secondly, it is worth noting that policy implementation has prioritized the eastern regions of China, resulting in longer and more extensive exposure to the policies. Consequently, the impact of these policies is relatively stronger in the eastern region compared to the central and western regions. Thirdly, the high concentration of firms in the east implies greater competition and a higher level of pressure to comply with the Air Quality Standards (AQS). Moreover, the ambient air quality in the eastern region is generally better compared to other regions. As a result, the policy measures have had a more pronounced effect on improving investment efficiency for firms in the eastern region. Taking these factors into account, the differential impact of the policy implementation across regions can be attributed to the distribution of firms, the duration and intensity of policy implementation, and the existing environmental conditions within each region.

Table 12
Parallel Trend Tests.

	(1)
Variables	Absinv
Pre_2	−0.00346
	(−0.79)
Pre_1	−0.00435
	(−0.92)
Current	−0.00914*
	(−1.91)
Post_1	−0.01084**
	(−2.48)
Post_2	−0.00422
	(−0.71)
Controls	YES
Observations	16,845
R-squared	0.244
Firm FE	YES
Year FE	YES
Cluster	Firm
Adj. R-squared	0.123

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

Table 13
Controlling for Province-by-Year Fixed Effects.

	(1)	(2)	(3)
Variables	Absinv	Absinv	Absinv
Post×Treat	−0.00862**	−0.00247	−0.00532*
	(−2.11)	(−0.31)	(−1.96)
Size	0.02878***	0.07000***	−0.00526**
	(2.68)	(3.04)	(−2.26)
Lev	0.02815	0.10807**	0.00273
	(1.00)	(2.04)	(0.29)
ROA	0.10305**	0.10285	0.13088***
	(2.55)	(1.11)	(5.80)
Cashflow	−0.05197***	−0.03387	−0.04316***
	(−3.32)	(−0.83)	(−3.89)
Growth	0.02702***	0.05331***	0.00247
	(4.33)	(4.21)	(1.34)
Board	−0.00814	−0.02202	0.00944
	(−0.93)	(−1.03)	(1.15)
Indep	−0.01543	0.00862	0.01556
	(−0.52)	(0.13)	(0.67)
Dual	−0.00483	−0.02367	0.00150
	(−1.09)	(−1.46)	(0.60)
BM	−0.00713***	−0.01290*	−0.00126
	(−2.68)	(−1.68)	(−1.31)
FirmAge	−0.03115*	−0.00246	−0.01926*
	(−1.94)	(−0.04)	(−1.68)
Top1	0.01639	0.07170	−0.01629
	(0.41)	(0.73)	(−1.30)
Mshare	−0.01919	−0.03560	−0.01012
	(−0.52)	(−0.26)	(−0.81)
Observations	16,845	6436	9860
R-squared	0.257	0.507	0.380
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Province by Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.118	0.277	0.174

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

6. Conclusion

To address the environmental risks, China in recent decades has implemented regulations aimed at curbing corporate emissions (e.g., Gu et al., 2021, 2022; Yan et al., 2022). Although such policies can be effective in reducing air pollutions and other environmental hazards, we know little about the impact on firm investment efficiency, a key indicator of firm growth and resource allocation.

Our study focuses on Chinese A-share listed firms for the period between 2007 and 2017 to examine the impact of a recent government policy that strengthened corporate green disclosure on firm investment inefficiency. We find that the implementation of AQS has substantially

Table 14
Further analysis.

	(1)	(2)	(3)
Variables	Western	Central	Eastern
Post×Treat	0.00075	−0.01276	−0.01096**
	(0.11)	(−1.34)	(−2.36)
Size	0.01525**	0.00248	0.03921**
	(2.01)	(0.31)	(2.43)
Lev	−0.01867	−0.01490	0.04352
	(−0.67)	(−0.37)	(1.14)
ROA	0.08321*	0.18212***	0.06909
	(1.78)	(3.38)	(1.18)
Cashflow	−0.03560	−0.02440	−0.06018***
	(−1.20)	(−0.78)	(−2.86)
Growth	0.01758***	0.01771*	0.03326***
	(3.47)	(1.66)	(3.69)
Board	−0.00070	−0.01709	−0.00091
	(−0.03)	(−0.98)	(−0.08)
Indep	−0.08595	−0.03482	0.00639
	(−1.59)	(−1.00)	(0.15)
Dual	0.00599	0.00287	−0.00886
	(1.01)	(0.53)	(−1.52)
BM	−0.01009***	−0.00366	−0.00658*
	(−3.22)	(−1.50)	(−1.66)
FirmAge	−0.01477	−0.00937	−0.03173
	(−0.42)	(−0.30)	(−1.61)
Top1	0.00859	0.00871	0.02523
	(0.26)	(0.29)	(0.43)
Mshare	−0.01720	0.06123**	−0.03482
	(−0.55)	(2.27)	(−0.79)
Observations	2352	3170	11,313
R-squared	0.317	0.258	0.246
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R-squared	0.205	0.140	0.121

Notes: We report t-statistics based on robust standard errors clustered by firm in parentheses, while ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.

increased firm investment efficiency and such effect is largely driven by a reduction in firm underinvestment. Further analyses reveal more nuanced findings. We find that the AQS-investment efficiency nexus is mitigated by state and institutional ownership and is operating through a reduction in agency problems and an improvement in firm access to external finance.

The paper's focus on the detrimental effects of energy-related environmental pollution and its connection to corporate costs highlights the extreme risks associated with environmental degradation. Extreme events, such as episodes of heavy pollution, pose immediate and severe risks to public health, infrastructure, and economic/financial stability. By examining how environmental policies, like the AQS, influence investment efficiency, the study contributes insights into managing extreme environmental risks within the energy sector.

Specifically, this study makes two key contributions. Firstly, it adds to the growing body of research on the negative effects of energy-related pollution and the role of environmental policies, like the AQS, in reducing air pollution and mitigating its impact on psychological and mental health (Dominici et al., 2006; Chen et al., 2013; Levinson, 2012). While complying with sustainability requirements may incur higher costs for firms, our findings suggest that the implementation of the AQS, instead of inhibiting firm growth, actually increases firm investment efficiency. This demonstrates that careful policy design can achieve both environmental protection and firm growth.

Secondly, our research contributes to the literature on firm investment inefficiency. Previous studies have examined various factors influencing investment efficiency, such as corporate governance, financial relationships, and the business environment (Chen et al., 2011b; Wang et al., 2020). However, the impact of corporate sustainability policies on investment efficiency remains under-researched. By studying the effects of the AQS, which strengthens green disclosure, our study provides unique insights into the relationship between sustainability policies and investment efficiency, expanding our understanding in this area.

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Compliance with ethical standards

All authors declare that he has no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Data availability

Data available on request from the authors.

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Appendix A. Supplementary data

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