Economics Letters 215 (2022) 110490

Contents lists available at ScienceDirect

Economics Letters

journal homepage: www.elsevier.com/locate/ecolet

Does air pollution impair investment efficiency?

Guanming He [a,*], Tiantian Lin [a,b]

[a] Durham University Business School, Durham University, United Kingdom
[b] School of Economics and Management, Beijing Jiaotong University, China

ARTICLE INFO

Article history:
Received 11 March 2022
Received in revised form 22 March 2022
Accepted 3 April 2022
Available online 11 April 2022

JEL classification:
G31
Q53

Keywords:
Air pollution
Investment efficiency

ABSTRACT

Using a sample of 2174 Chinese listed firms for the period 2014–2019, we examine whether air pollution impairs investment efficiency of firms. We find robust evidence that air pollution is negatively associated with firms' investment efficiency, and that this association is more pronounced for small firms, non-state-owned firms, financially constrained firms, and firms confronted with high business risk or intense industrial product market competition.

1. Introduction

As an undesirable health risk factor, air pollution has been the spotlight in the academic research in the recent years. Prior studies suggest that air pollution has negative impact on human in terms of psychology (Evans et al., 1988), mood (Lundberg, 1996; Zhang and Zhang, 2017), physical health (Kampa and Castanas, 2008) as well as life satisfaction (Luechinger, 2010). Air pollution undermines individuals' work efficiency (Graff Zivin and Neidell, 2012; Chang et al., 2016) via eroding their cognitive performance in information processing (Chen and Schwartz, 2009) and causing mood-induced emotional decision-making (Lucey and Dowling, 2005). Recent research examines the relationship of air pollution with stock trading behavior (Huang et al., 2020), analyst forecasts (Dong et al., 2021), and corporate social responsibility (Liu et al., 2022). We extend this line of research by investigating whether air pollution weakens corporate investment efficiency. China provides a nice setting to examine this issue since the degree of air pollution varies substantially across cities and years.

We expect that air pollution adversely impacts managers' mood, judgement, and decision-making on corporate investments, and thereby reduces the investment efficiency of firms. Consistent with this expectation, we find strong and robust evidence that firms headquartered in a city with worse air quality have lower investment efficiency. To the best of our knowledge, our study is the first to provide empirical evidence for the negative effect of air pollution on firms' investment efficiency. Our findings imply the importance of improving air quality to ameliorate investment decision-making and having investment decisions re-checked by managers whose work base is not in the air-polluted city where the company is headquartered.

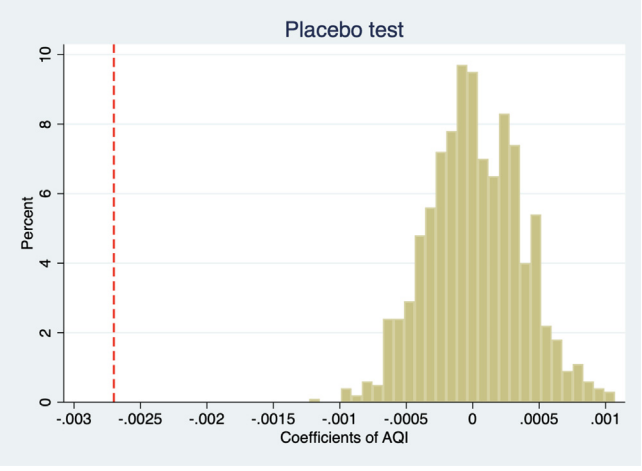

Fig. 1. Distribution of the 1000 coefficient estimates in a placebo test. Notes: *X*-axis presents the coefficients of *AQI*, and *Y*-axis presents the percentage of coefficients that fall within the bin. The yellow-bar charts show the estimated coefficients of *AQI* in the placebo test, while the red dotted line shows the estimated coefficient of *AQI* in the baseline regression analysis.

2. Data

Our analysis is based on a sample of Chinese firms listed on the Shanghai or Shenzhen Stock Exchange. Our sample period

* Corresponding author.
E-mail addresses: guanming.he@durham.ac.uk (G. He), 18113011@bjtu.edu.cn (T. Lin).

https://doi.org/10.1016/j.econlet.2022.110490

Table 1
The impact of air pollution on corporate investment efficiency.

Variables	(1) *Invest_efficiency*	(2) *Overinvest_efficiency*	(3) *Underinvest_efficiency*
AQI	−0.0027***	−0.0038***	−0.0018***
	(−3.76)	(−3.92)	(−2.66)
Tobin − Q	−0.0004*	−0.0003	−0.0005**
	(−1.83)	(−0.94)	(−2.28)
Sale_growth	−0.0006	−0.0007	−0.0006
	(−1.63)	(−1.12)	(−1.47)
Leverage	−0.0034**	−0.0034	−0.0030*
	(−1.99)	(−1.40)	(−1.80)
ROA	−0.0021	−0.0029	0.0036
	(−0.44)	(−0.40)	(0.74)
Asset_turnover	0.0006	−0.0001	0.0013*
	(0.77)	(−0.07)	(1.84)
Cash	−0.0040**	−0.0122***	−0.0004
	(−2.31)	(−4.06)	(−0.29)
LnAsset	0.0010***	0.0014***	0.0007**
	(3.26)	(3.49)	(2.35)
Tangibility	−0.0203***	−0.0207***	−0.0167***
	(−3.57)	(−2.79)	(−3.00)
LnBoard_size	−0.0012	−0.0022	−0.0004
	(−0.77)	(−1.11)	(−0.25)
Board_independence	−0.0062	−0.0137*	−0.0015
	(−1.12)	(−1.86)	(−0.28)
Institutional_ownership	−0.0023	−0.0023	−0.0030**
	(−1.52)	(−1.07)	(−2.04)
Managerial_ownership	−0.0033	−0.0022	−0.0051**
	(−1.30)	(−0.65)	(−2.00)
SOE	0.0041***	0.0049***	0.0034***
	(5.95)	(5.55)	(5.30)
Firm_age	0.0007	0.0002	0.0010*
	(1.14)	(0.26)	(1.71)
Stock_return	−0.0016***	−0.0044***	−0.0002
	(−3.89)	(−5.19)	(−0.37)
INTERCEPT	−0.0248***	−0.0251***	−0.0244***
	(−3.33)	(−2.58)	(−3.38)
Industryfixedeffects	included	included	included
Yearfixedeffects	included	included	included
N	10,920	4,885	6,035
Adj.R^2	0.0754	0.0873	0.0809

Notes: t-statistics in parentheses are based on robust standard errors clustered by firm . All the variables are defined in Table A.1. ***, **, and * indicate the 1%, 5%, and 10% two-tailed statistical significance, respectively.

starts from 2014, the year in which the air quality index (AQI) was constructed and published by the Ministry of Environment Protection of China for most cities in China. We use AQI rather than the level of fine particulate matter (namely, PM2.5) to measure the degree of air pollution since AQI captures the levels of six main air pollutants including PM2.5. We end our sample period in 2019, the year before the outbreak of COVID-19 pandemic.

The financial, governance, and stock market data are extracted from the Chinese Stock Market and Accounting Research Database to construct variables for our multivariate tests. All variables are winsorized at the 1% and 99%, respectively, and defined in Table A.1. We introduce our sample selection procedure in Table A.2. Our final sample consists of 10,920 firm-year observations for 2174 firms headquartered in 230 cities. The distributions of the variables for investment efficiency and air pollution are provided in Table A.3, and the univariate statistics are reported in Table A.4.

3. Research design and results

3.1. Baseline regression analysis

To test the impact of air pollution on firms' investment efficiency, we employ the following ordinary least square (OLS) regression model:

$$\begin{aligned} Invest\_efficiency_{i,t} = {} & \alpha + \beta AQI_{i,t} + \gamma Controls_{i,t-1} \\ & + \sum Industry\ fixed\ effects \\ & + \sum Year\ fixed\ effects + \epsilon_{i,t} \end{aligned} \tag{1}$$

$Invest\_efficiency_{i,t}$ is investment efficiency of firm i at year t, which is measured as -1 times the absolute value of the residual of the regression model developed by Richardson (2006). In applying the Richardson's model, we use Tobin's Q as the proxy for a firm's growth prospect. A higher value of *Invest_efficiency* denotes higher investment efficiency of the firm. We also divide our measurement of investment efficiency into overinvestments (*Overinvest_efficiency*) and under-investments (*Underinvest_efficiency*) by a firm for additional regression analysis. $AQI_{i,t}$ equals the average daily air quality index of firm i at year t, divided by the standard deviation of the daily air quality index in the city where the company is headquartered. The air quality index is constructed in a way such that a higher value of $AQI_{i,t}$ denotes worse air quality. We include a battery of control variables for investment efficiency, based on the extant literature (e.g., Rajkovic, 2020), alongside with industry dummies and year dummies in the regression.

Table 2
Robustness checks.

	Alternative measures of investment efficiency		Alternative measure of air pollution	Firm-fixed-effects regression	2SLS regression	
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	*Invest_efficiency_robust*1	*Invest_efficiency_robust*2	*Invest_efficiency*	*Invest_efficiency*	*AQI*	*Invest_efficiency*
AQI	−00027***	−0.0027***		−0.0018**		
	(−3.80)	(−3.90)		(−2.27)		
AQI_robust			−0.0018*			
			(−1.83)			
Humidity					0.0158***	
					(23.88)	
Greencover					−0.3196**	
					(−1.96)	
Pred_AQI						−0.0041**
						(−2.51)
Controls	included	included	included	included	included	included
Industryfixedeffects	included	included	included	included	included	included
Yearfixedeffects	included	included	included	included	included	included
Firmfixedeffects				included		
N	10,920	10,808	10,920	10,920	10,851	10,851
Adj.R^2	0.0756	0.0739	0.0734	0.4421	0.2425	0.0740
Test of overidentification (p-value)					0.3352	

Notes: t-statistics in parentheses are based on robust standard errors clustered by firm. All the variables are defined in the Table A.1. ***, **, and * indicate the 1%, 5%, and 10% two-tailed statistical significance, respectively.

Table 3
Moderation analysis.

Dependent variable = *Invest_efficiency*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Small companies (*LnAsset*)	Big Companies (*LnAsset*)	Non-state-owned enterprises (*SOE*)	State-owned enterprises (*SOE*)	High financial constraints (*Finconstra*)	Low financial constraints (*Finconstra*)	High business risk (*VarROA*)	Low business risk (*VarROA*)	High industrial competition (*Competition*)	Low industrial competition (*Competition*)
AQI	−0.0037***	−0.0017*	−0.0036***	−0.0011	−0.0037***	−0.0022**	−0.0035***	−0.0019**	−0.0041***	−0.0015
	(−3.70)	(−1.92)	(−3.80)	(−1.06)	(−3.54)	(−2.40)	(−3.52)	(−2.28)	(−4.27)	(−1.50)
Coefficientdifference		−0.0020***		−0.0025***		−0.0015**		−0.0016**		−0.0026***
Controls	included	included	included	included	included	included	included	included	included	included
Industryfixedeffects	included	included	included	included	included	included	included	included	included	included
Yearfixedeffects	included	included	included	included	included	included	included	included	included	included
N	5,461	5,458	7,337	3,583	4,716	4,716	5,460	5,460	5,378	5,542
Adj.R^2	0.0708	0.0701	0.0583	0.0692	0.0709	0.089	0.0638	0.0905	0.0689	0.0880

Notes: t-statistics in parentheses are based on robust standard errors clustered by firm. All the variables are defined in the Table A.1. ***, **, and * indicate the 1%, 5%, and 10% two-tailed statistical significance, respectively.

Table A.1
Definitions of variables.

Variables	Definition
Invest_efficiency	investment efficiency of a listed firm in a year, which is measured as −1 times the absolute values of the residuals of a regression model developed by Richardson (2006) and using Tobin's Q as the proxy for growth opportunities. A higher value of *Invest_efficiency* denotes higher investment efficiency.
Overinvest_efficiency	overinvestment efficiency of a listed firm in a year, which is measured as −1 times the values of the positive residuals of a regression model developed by Richardson (2006) and using Tobin's Q as the proxy for growth opportunities. A higher value of *Overinvest_efficiency* denotes higher investment efficiency with a lower degree of overinvestments by the firm.
Underinvest_efficiency	under-investment efficiency of a listed firm in a year, which is measured as −1 times the absolute values of the negative residuals of a regression model developed by Richardson (2006) and using Tobin's Q as the proxy for growth opportunities. A higher value of *Underinvest_efficiency* denotes higher investment efficiency with a lower degree of under-investments by the firm.
*Invest_efficiency_robust*1	investment efficiency of a listed firm in a year, which is measured as −1 times the absolute values of the residuals of a regression model developed by Richardson (2006) and using sales growth as the proxy for growth opportunities. The sales growth is defined as the change in sales from the previous year to the current year divided by the sales in the previous year. A higher value of *Invest_efficiency_robust*1 denotes higher investment efficiency.
*Invest_efficiency_robust*2	investment efficiency of a listed firm in a year, which is measured as −1 times the absolute values of the residuals of a regression model developed by Richardson (2006), using Tobin's Q as the proxy for growth opportunities, augmented by the industrial sales growth rate. A higher value of *Invest_efficiency_robust*2 denotes higher investment efficiency.
AQI	the average daily air quality index, divided by the standard deviation of daily air quality index in the city where the company is headquartered, in a year. Air quality index is built and published by the Ministry of Environment Protection of China, based on the levels of six main pollutants — fine particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), fine particulate matter smaller than 10 micrometers (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), Ozone (O_3), and carbon monoxide (CO). A higher value of *AQI* denotes worse air quality.
AQI_robust	the average daily air quality index, divided by the standard deviations of daily air quality index in the province where the company is headquartered, in a year. Air quality index is built and published by the Ministry of Environment Protection of China, based on the levels of six main pollutants — fine particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), fine particulate matter smaller than 10 micrometers (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), Ozone (O_3), and carbon monoxide (CO). A higher value of *AQI_robust*1 denotes worse air quality.
Tobin − Q	the ratio of the market value of assets to the book value of assets for a firm at the end of a year.
Sale_growth	the difference between sales revenue for the year and that for the prior year, divided by sales revenue for the prior year, for a firm.
Leverage	the ratio of total liabilities to total assets for a firm at the end of a year.
ROA	the ratio of earnings before interests and taxes to average assets for a firm for a year.
Asset_turnover	the ratio of total sales to average assets for a firm for a year.
Cash	the ratio of cash and short-term investments deflated by total assets measured at the start of a year for a firm.
LnAsset	the natural logarithm of total assets for a firm at the start of a year.
Tangibility	the ratio of intangible assets to total assets for a firm at the end of a year.
LnBoard_size	the natural logarithm of the number of board members for a firm at the end of a year.
Board_independence	the ratio of the number of independent directors to the total number of board members for a firm at the end of a year.
Institutional_ownership	the ratio of the number of shares held by institutional investors to the total shares outstanding for a firm at the end of a year.
Managerial_ownership	the ratio of the number of shares held by executives to the total shares outstanding for a firm at the end of a year.
SOE	1 if the largest ultimate shareholder of a firm pertains to a government entity, and 0 otherwise.
Firm_age	the natural logarithm of one plus the number of years since the firm was listed on the stock market in mainland China.
Stock_return	annual stock return of a firm in a year, with cash dividends reinvested for the firm over the prior year.
Humidity	the average daily humidity in the city where the company is headquartered in a year.
Greencover	the average fraction of the public green space of the city, in which the company is headquartered, in a year. The average is taken of the fraction of the green space at the end of the year and that at the beginning of the year. The data used for constructing *Greencover* come from the China City Statistical Yearbook.
VarROA	the standard deviation of returns on assets for a firm for the recent 5 years.
Finconstra	the WW index which is developed by Whited and Wu (2006), and is constructed based on a linear combination of six factors: cash flows, dividend payout, financial leverage, firm size, industrial sales growth, and corporate sales growth, for a firm for a year.
Competition	the Herfindahl–Hirschman Index (HHI), which is calculated by summing the squared ratios of operating revenue of each company in an industry to the total operating revenue of the industry.

As reported in Column (1) of Table 1, the coefficient of *AQI* is negative and statistically significant. A one-standard-deviation increase in *AQI* reduces *Invest_efficiency* by 0.00096, which accounts for 5.8297% of the mean of *Invest_efficiency* and is thus economically significant. This result suggests that high air pollution reduces investment efficiency of firms. We also find evidence, shown in Columns (2) and (3), that air pollution exacerbates either over-investments or under-investments by firms.

Table A.2
Sample selection procedure.

	Number of firm-year observations
Observations of the whole population of companies listed on the Shenzhen or Shanghai Stock Exchange in the years 2014–2019	18,667
Less: observations of firms in the financial industry	(525)
Less: observations of firms labeled with ST and ST*	(930)
Less: observations of firms with B shares	(95)
Less: observations of firms cross-listed overseas (excluding those cross-listed on the Hong Kong Stock Exchange)	(67)
Less: observations with missing values in regressors	(5,825)
- observations without values of Tobin's Q	(797)
- observations without values of sales growth	(870)
- observations without values of assets	(1)
- observations without values of stock returns	(206)
- observations without values of board size	(3,546)
- observations without values of institutional shareholding	(8)
- observations without information on state-owned property	(245)
- observations without values of air quality index	(152)
Less: firms with only one observation	(305)
Final observations	10,920
Unique companies	2,174
- Unique companies on the Shenzhen Stock Exchange	1,393
- Unique companies on the Shanghai Stock Exchange	781

Table A.3
Distribution of investment efficiency and air quality index.

Panel A: The mean values of investment efficiency and air quality index by year			
Variables	*Invest_efficiency*	*AQI*	*N*
2014	−0.0524	2.2110	1,585
2015	−0.0458	2.2088	1,670
2016	−0.0431	2.2629	1,732
2017	−0.0436	2.1925	1,896
2018	−0.0452	2.2135	2,004
2019	−0.0408	2.2785	2,033
Panel B: The mean values of investment efficiency and air quality index by industry			
Variables	*Invest_efficiency*	*AQI*	*N*
Farming, forestry, animal husbandry, and fishery	−0.0710	2.1889	116
Mining	−0.0512	2.1318	229
Manufacturing	−0.0488	2.2405	6,849
Production and supply of electric power, gas, and water	−0.0591	2.1086	303
Construction	−0.0207	2.1432	295
Wholesale and retail trade	−0.0283	2.2723	618
Traffic, storage, and mail business	−0.0607	2.2668	305
Accommodation and food	−0.0307	1.9133	23
Information transfer, computer service, and software	−0.0368	2.1964	902
Real estate	−0.0111	2.2727	485
Leasehold and business service	−0.0374	2.2562	207
Scientific research, technical service, and geologic examination	−0.0572	2.1568	84
Water conservancy, environment, and public institution management	−0.0802	2.1807	178
Education	−0.0415	2.1438	37
Health and social work	−0.0504	2.2236	52
Cultural or physical entertainments	−0.0237	2.2243	179
Other service activities	−0.0290	2.1792	58

Notes: This table presents the distribution of investment efficiency and air quality index by year and industry. The sample period ranges from 2014 to 2019.

3.2. Robustness checks

For robustness check of our baseline results, we employ alternatives measures of investment efficiency (i.e., *Invest_efficiency_robust*1 and *Invest_efficiency_robust*2) and air pollution (i.e., *AQI_robust*). *Invest_efficiency_robust*1 is constructed by using sales growth as the proxy for a firm's growth prospect. *Invest_efficiency_robust*2 is constructed by adding industrial sales growth as an additional control in the Richardson's (2006) model and using Tobin's Q as the proxy for a firm's growth prospect. *AQI_robust* equals the average daily air quality index of a province where a company is headquartered in a year. The results under these alternative measurements are reported in Columns (1–3) of Table 2 and remain qualitatively the same as those reported in Table 1.

To mitigate the concern about potential endogeneity, we perform a firm-fixed-effects regression analysis, a two-stage least-squares (2SLS) regression analysis, and a placebo test, respectively. The firm-fixed-effects regression results, reported in Column (4) of Table 2, elicit the same inferences as do the baseline regression results. For the 2SLS regression estimation, we use the green space coverage (*Greencover*) and humidity (*Humidity*)

Table A.4
Univariate statistics.

Panel A: Descriptive statistics[a]

Variables	N	Mean	Std	P10	P25	P50	P75	P90
Invest_efficiency	10,920	−0.0164	0.0181	−0.0016	−0.0039	−0.0102	−0.0218	−0.0396
AQI	10,920	2.2287	0.3541	1.7326	1.9832	2.2413	2.4631	2.6398
Tobin − Q	10,920	2.1619	1.4228	1.0693	1.2858	1.7108	2.4697	3.7007
Sale_growth	10,920	0.2219	0.5301	−0.1496	−0.0052	0.1212	0.2941	0.5841
Leverage	10,920	0.4382	0.2046	0.1688	0.2743	0.4294	0.5908	0.7164
ROA	10,920	0.0412	0.0557	0.0019	0.0145	0.0370	0.0686	0.1047
Asset_turnover	10,920	0.6403	0.4397	0.2245	0.3508	0.5433	0.7964	1.1485
Cash	10,920	0.2024	0.1515	0.0608	0.0991	0.1602	0.2571	0.4045
LnAsset	10,920	22.2172	1.2797	20.6917	21.3081	22.0637	22.9722	23.9306
Tangibility	10,920	0.0473	0.0520	0.0051	0.0173	0.0344	0.0578	0.0955
LnBoard_size	10,920	2.1272	0.1954	1.9459	1.9459	2.1972	2.1972	2.3979
Board_independence	10,920	0.3761	0.0540	0.3333	0.3333	0.3636	0.4286	0.4286
Institutional_ownership	10,920	0.4414	0.2411	0.0829	0.2461	0.4636	0.6353	0.7500
Managerial_ownership	10,920	0.0934	0.1552	0.0000	0.0000	0.0008	0.1436	0.3541
SOE	10,920	0.3281	0.4695	0.0000	0.0000	0.0000	1.0000	1.0000
LnFirm_age	10,920	2.3683	0.6207	1.3863	1.9459	2.3979	2.9444	3.1355
Stock_return	10,920	0.1418	0.5716	−0.4078	−0.2654	−0.0170	0.3956	0.8810

Panel B: Correlation matrix[b]

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) *Invest_efficiency*	1																
(2) *AQI*	−0.043***	1															
(3) *Tobin − Q*	−0.094***	0.040***	1														
(4) *Sale_growth*	−0.061***	0.012	0.027***	1													
(5) *Leverage*	0.122***	−0.021**	−0.419***	−0.004	1												
(6) *ROA*	−0.070***	0.047***	0.265***	0.308***	−0.395***	1											
(7) *Asset_turnover*	0.000	0.090***	0.001	0.155***	0.114***	0.245***	1										
(8) *Cash*	−0.026***	−0.004	0.201***	0.159***	−0.238***	0.292***	0.092***	1									
(9) *LnAsset*	0.161***	−0.070***	−0.609***	−0.036***	0.516***	−0.096***	0.047***	−0.207***	1								
(10) *Tangibility*	−0.150***	−0.056***	0.043***	−0.026***	−0.114***	−0.013	0.034***	−0.114***	−0.060***	1							
(11) *LnBoard_size*	0.036***	−0.047***	−0.147***	−0.038***	0.131***	−0.016*	0.051***	−0.061***	0.236***	0.031***	1						
(12) *Board_independence*	−0.001	0.001	0.019**	0.001	−0.011	−0.028***	−0.045***	0.015	−0.017*	−0.005	−0.597***	1					
(13) *Institutional_ownership*	0.070***	−0.038***	−0.172***	−0.028***	0.210***	0.072***	0.091***	−0.002	0.417***	−0.030***	0.163***	−0.036***	1				
(14) *Managerial_ownership*	−0.130***	0.062***	0.172***	0.186***	−0.310***	0.193***	−0.023**	0.152***	−0.365***	0.039***	−0.162***	0.037***	−0.592***	1			
(15) *SOE*	0.158***	−0.111***	−0.243***	−0.155***	0.279***	−0.147***	0.035***	−0.097***	0.383***	−0.010	0.241***	−0.049***	0.380***	−0.516***	1		
(16) *LnFirm_age*	0.153***	−0.016*	−0.204***	−0.157***	0.358***	−0.202***	−0.031***	−0.175***	0.422***	−0.092***	0.155***	−0.050***	0.244***	−0.577***	0.453***	1	
(17) *Stock_return*	−0.071***	0.026***	0.355***	0.033***	−0.025***	0.132***	0.061***	0.110***	−0.139***	0.019*	0.023**	−0.023**	0.065**	−0.012	0.003	−0.092***	1

[a]Notes: This table reports descriptive statistics for the regressors used in the tests of the impact of air pollution on investment efficiency. The sample period ranges from 2014 to 2019. Definitions for the variables are provided in Table A.1.

[b]Notes: This table reports Spearman correlation for the regressors used in the tests of the impact of air pollution on investment efficiency. The sample period ranges from 2014 to 2019. ***, **, and * indicate 1%, 5%, and 10% two-tailed statistical significance, respectively. Definitions for the variables are provided in Table A.1.

of the city, in which a company is headquartered, as the instrumental variables. While high coverage of public green space in a city improves air quality (Diener and Mudu, 2021), high humidity would lead to high concentrations of particulate matters and poor air quality (Xu et al., 2018). The first-stage regression results, reported in Column (5) of Table 2, suggest that the green space coverage (humidity) indeed reduces (aggravates) air pollution. The Cragg–Donald Wald F statistic for the instrumental variables amounts to 1403.304 and is higher than the threshold point of 11.59 proposed by Stock et al. (2002), thus refuting the possibility that our instruments are weak. In un-tabulated analysis, we include *Greencover* and *Humidity* as additional controls in the baseline regression, and find statistically insignificant coefficients on these two variables. This result suggests that the green space coverage and humidity do not have direct impacts on firms' investment efficiency and are thus valid instruments for our 2SLS regression estimation. The second-stage results, shown in Column (6), are consistent with those in Table 1.

To carry out the placebo test, we replace the city, in which a firm is headquartered, with a randomly selected city outside of the firm's headquarter province so as to re-construct a placebo variable for air pollution. We repeat the random selection, construct the associated variable, and estimate its coefficient by 1000 times. Fig. 1 plots the distribution of the 1000 coefficient estimates. The mean value of the estimated coefficients has a t-statistic equal to 0.0545, and is not significantly different from 0. This result suggests that our baseline results for *AQI* are unlikely to be driven by correlated omitted variable(s).

3.3. Cross-sectional analysis

We further test whether our baseline regression results vary by company size, state-owned property, financial constraint, business risk, and industrial product market competition. To this end, we split our full sample into two subsamples based on the sample median of the continuous variables for firm size (*LnAsset*), financial constraint (*Finconstra*), business risk (*VarROA*), and industrial product market competition (*Competition*), respectively, and on the binary variable for whether a firm is state-owned (*SOE*). Table 3 reports the results. The differences in the negative coefficients on *AQI* between each pair of subsamples are all statistically significant. These findings suggest that the negative impact of air pollution on firms' investment efficiency is stronger for small firms, non-state-owned firms, financially constrained firms, and firms faced with high business risk or fierce industrial competition.

4. Conclusion

Based on a sample of 2174 Chinese listed firms for the years 2014–2019, we find strong and robust evidence that air pollution is negatively associated with firms' investment efficiency. This finding underscores the importance of reducing air pollution, given the essential role of corporate investments in promoting a country's economic growth.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

We thank an anonymous reviewer for helpful comments and suggestions on the paper.

Appendix A. Supplementary results for the paper, titled "does air pollution impair investment efficiency?"

See Tables A.1–A.4

References

Chang, T., Zivin, J.Graff., Gross, T., Neidell, M., 2016. Particulate pollution and the productivity of pear packers. Am. Econ. J.: Econ. Policy 8 (3), 141–169.
Chen, J.S., Schwartz, J., 2009. Neurobehavioral effects of ambient air pollution on cognitive performance in US adults. Neurotoxicology 30 (2), 231–239.
Diener, A., Mudu, P., 2021. How can vegetation protect us from air pollution? A critical review on green spaces' mitigation abilities for air-borne particles from a public health perspective-with implications for urban planning. Sci. Total Environ. 796, 148605.
Dong, R., Fisman, R., Wang, Y., Xu, N., 2021. Air pollution, affect, and forecasting bias: Evidence from Chinese financial analysts. J. Financ. Econ. 139 (3), 971–984.
Evans, G.W., Colome, S.D., Shearer, D.F., 1988. Psychological reactions to air pollution. Environ. Res. 45 (1), 1–15.
Graff Zivin, J., Neidell, M., 2012. The impact of pollution on worker productivity. Amer. Econ. Rev. 102 (7), 3652–3673.
Huang, J., Xu, N., Yu, H., 2020. Pollution and performance: Do investors make worse trades on hazy days? Manage. Sci. 66 (10), 4455–4476.
Kampa, M., Castanas, E., 2008. Human health effects of air pollution. Environ. Pollut. 151 (2), 362–367.
Liu, J., Pan, X., Qu, Y., Wang, C., Wu, W., 2022. Air pollution, human capital and corporate social responsibility performance: Evidence from China. Appl. Econ. 54 (4), 467–483.
Lucey, B.M., Dowling, M., 2005. The role of feeling in investor decision-making. J. Econ. Surv. 19 (2), 211–237.
Luechinger, S., 2010. Life satisfaction and transboundary air pollution. Econom. Lett. 107 (1), 4–6.
Lundberg, A., 1996. Psychiatric aspects of air pollution. Otolaryngol. Head Neck Surg. 114 (2), 227–231.
Rajkovic, T., 2020. Lead independent directors and investment efficiency. J. Corporate Finance 64, 101690.
Richardson, S., 2006. Over-investment of free cash flow. Rev. Account. Stud. 11 (2), 159–189.
Stock, J.H., Wright, J.H., Yogo, M., 2002. A survey of weak instruments and weak identification in generalized method of moments. J. Bus. Econom. Statist. 20 (4), 518–529.
Whited, T.M., Wu, G., 2006. Financial constraints risk. Rev. Financ. Stud. 19 (2), 531–559.
Xu, Y., Xue, W., Lei, Y., Zhao, Y., Cheng, S., Ren, Z., Huang, Q., 2018. Impact of meteorological conditions on PM2.5 pollution in China during winter. Atmosphere 9 (11), 429.
Zhang, X., Zhang, X., 2017. Valuing air quality using happiness data: The case of China. Ecol. Econom. 137, 29–36.