Brain Drain: The Impact of Air Pollution on Firm Performance

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March 2019

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JEL Classification: O3, Q5, J3

Keywords: Air pollution, Human Capital, Brain Drain, Firm Performance, Innovation, Central Heating Policy, China

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1. Introduction

Corporate human capital is an essential element of value creation and success of firms. Investing in human capital is widely viewed as a key to sustaining an increase in corporate innovation and work productivity. Air pollution is known to affect human health that is increasingly seen as a part of human capital (Graff Zivin and Neidell, 2012). An extensive literature finds that ambient air pollution may cause adverse impacts on human health, such as premature death and shortened lives (Chen *et al.*, 2013; Tanaka, 2015), and is listed as the single largest environmental health risk (see, European Environment Agency, 2015). Indeed, the worsening air quality in developing countries, such as China, in recent years has provoked a great public concern, which drives skilled individuals to leave and dissuades talent from coming. Insofar as such effects are substantial, there has been surprisingly little direct analysis of how air pollution may affect corporate human capital; for example, the accumulation of executive talent and skilled employees. Understanding the magnitude of this effect is vital for firms to response in developing strategies to secure human capital to achieve competitive advantages and long-term growth. It also has significant implications for regulators in designing optimal environmental policy given the benefits of clean air are less well understood.

Our intuition is built on Tiebout's (1956) model that individuals have heterogeneous preferences for public goods and sort into localities that most closely match those preferences. In line with this view, previous literature finds that regional amenities are positively associated with land rents and regional wages (Chay and Greenstone, 2005; Sullivan, 2016). Banzhaf and Walsh (2008) find more direct evidence on this view by showing that the entry of polluting facilities in a region will cause emigration and the decline of population density. We expect that individuals' incentive to sort increases with their skills because educated and skilled people with high-income are more likely to desire for life quality than less-educated and -skilled people (Diamond, 2016; Liu and Shen, 2017). Moreover, when sorting to a distinct region, skilled people face a low risk of being unable to get re-employed and have low costs in searching a new job because they are more competitive in the labor market and have more information on job opportunities (Arntz, 2010; Borjas, 2014). As a result, the region-specific amenities are more likely to exert a more significant influence on individuals with high education and skills than those with low.

While economists have long recognized households' sorting response to the change of air quality, direct analysis of the impact of air pollution on the accumulation of human capital at firm level is scant mainly due to measurement difficulties. This paper is the first to rigorously assess the environmental corporate human capital effect. In specific, we examine whether firms located in polluted regions are less able to accumulate skilled executives and employees and how this "brain drain" effect affects firms' performance.

Examining the questions is challenging because ambient air pollution is associated with local business activities which in turn affect labor market opportunities. To deal with potential endogeneity problems, we use a regression discontinuity design (RDD) that exploits discontinuous variation in air pollution created by an arbitrary policy at the Qinling-Huai River boundary in China (Almond *et al.*, 2009). In 1950s-1980s, the Chinese government established a free coal-based central heating system for householders in North China, which is defined by the line formed by the Qinling Mountains and Huai River range (see Figure 1). The combustion of coal release massive particulate matter and other pollutants, which leads to a higher pollution level on the north of the boundary (Almond *et al.*, 2009; Chen *et al.*, 2013). The policy plausibly generates exogenous variation in air pollution that is independent of the consequence of business activities. Moreover, the policy has existed for a long time since the 1950s, which makes it particularly useful for studying activities with long-term impact (i.e., investment in human capital). We expect that firms located on the north of heating boundary have more exposure to air pollution and thus greater difficulty in recruiting and retaining high-quality human capital than those located on the south of the boundary.

We test the hypothesis based on firms publicly listed on China's two stock exchanges from 2000 to 2016. After performing various diagnostic tests to ensure that the key identifying assumptions of the RDD are satisfied, we find that air pollution has a negative effect on the quality of listed firms' human capital after controlling for a variety of firm and regional characteristics. Specifically, we assess the corporate human capital of both firm managers and employees as they may enter the production function and influence firm performance distinctly (Gennaioli *et al.*, 2013). Skilled executive talents are scarce. They have more job opportunities and thus are less likely to be restricted to the local job market. We thus measure the human capital of managers by gauging whether a firm's top executives (i.e., CEO and board chairman) were born or obtained colleague degrees outside the region where their firm domiciles, or had study and work experience abroad. Previous studies show that managers with diverse background and foreign experience are associated with better firm performance (Giannetti *et al.*, 2015; Chemmanur *et al.*, 2019).

Consistent with air pollution reducing attractiveness for skilled managers, we find that locating in the north, which is defined by the boundary of the coal-based heating system, leads to a 21% decline in the probability of having a non-locally born top executive, 14% decline in the probability of having a non-locally educated top executive, and 7% decline in the probability of having a top executive with overseas experience. The results suggest that air pollution makes it more difficult to recruit and retain executive talent from outside.

We then examine the impact on the human capital of firm employees. Previous studies suggest that highly-educated and skilled workers are important corporate human capital and significantly contribute to the improvement of firm productivity (Haltiwanger *et al.*, 1999; Ashraf and Ray, 2017). To test our hypothesis, we examine the association of air pollution with the proportion of high- and low-education employees and the proportion of skilled and non-skilled employees. This dynamic regression design offers a placebo test. Specifically, we find that the proportion of firm employees holding a bachelor degree or above in the north is 17% lower than that in the south; and the proportion of technical or skilled employees in the north is lowed by 15%. However, the proportions of low-education employees (i.e., those whose highest education level is high school or below) and non-technical employees (i.e., production and sales employees, and financial and administrative employees) have no significant distinction between the north and south sides of the heating border. The results are consistent with the importance of air quality amenity for high-quality employees.

To more explicitly identify the relation between the levels of air pollution and corporate human capital, we estimate a 2SLS where the air quality index (AQI) is instrumented by the notation of regions where the heating policy applies. We find that a poor level of air quality is associated with less accumulation of high-quality top executives and firm employees. To further address the concern of confounding regional factors, we re-estimate our models by focusing regions within a narrow margin along the central heating border. The results are highly robust. We also find consistent results when measuring the loss of human capital using regional migration information.

We then take a step further and examine whether the effect of air pollution is stronger in regions where public concern for amenity is more sensitive to air pollution. In Tiebout's sorting model, individuals have heterogeneous preferences for public goods and sort into locations that best match their preferences. To the extent that air pollution affects the accumulation of corporate human capital via its negative impact on life amenity, we expect the effect of air pollution on human capital will be stronger when individuals in a region have greater concern for amenity upon the emergence of bad air. To test this conjecture, we estimate a sensitivity of daily internet search volume by "health" on Baidu.com (Chinese Google) to the change of air quality in each region in a year. A more positive sensitivity means more attention to health upon the rise of air pollution, thus indicating a greater concern for amenity. We also estimate a sensitivity of search volume by "quit job" to the change of air quality. A more positive sensitivity indicates a greater aversion to disamenity and a stronger desire to flee current place and position. Indeed, we find that the two sensitivity measures are significantly positive, indicating that air pollution generally provokes public concerns for life amenity. Furthermore, we find the negative effects of air pollution on corporate human capital are stronger in regions where such sensitivity is higher, suggesting that air pollution affects corporate human capital through the amenity-concern sorting channel.

Thus far, our evidence suggests that there is a brain drain effect of air pollution in publicly listed firms. Next, we examine whether the brain drain effect manifests in firms' performance. Previous studies suggest that top management quality and employee skills are important determinants of corporate innovation (Ashraf and Ray, 2017; Chemmanur *et al.*, 2019), and corporate productivity (Haltiwanger *et al.*, 1999). We first examine the impact of human capital loss on corporate innovation and productivity. As expected, we find that firms located on the north side of the heating border have a significantly lower level of patents and patent efficiency (patents/R&D and patents/employees) than those on the south side. We also find the firms on the north side have a significantly lower level of total factor productivity. These results suggest that air pollution impedes corporate innovation and productivity. We further complement the analysis by examining the impact of air pollution on firm value and sales growth. Consistent with human capital's essential role for firm value creation and performance improvement (Chemmanur *et al.*, 2018), we find firms located in the polluted north regions indeed have a lower Tobin's Q and sales growth.

Lastly, we examine whether the effects of air pollution on firm performance is more pronounced in firms that depend on human capital more. We estimate the dependence of firm performance on human capital by regressing each of the performance measures (innovation, productivity, firm value, and sale growth) on the measure of executive talent and the proportion of high-quality employees in each industry over the past five years, respectively. We find that the effects of air pollution on firm performance is more pronounced in industries that have a higher estimated dependence on human capital. The results thus suggest that air pollution affects firm performance via the channel of human capital.

This paper contributes to human capital literature. We document an important non-economic factor that affects the accumulation of corporate human capital, while previous literature, mainly relying on regional analysis, focus on economic factors such as local wages and land rents (Rauch, 1993), organization change (Bresnahan *et al.*, 2002), financial deregulation (Philippon and Reshef, 2012), and local productivity change (Diamond, 2016). Moreover, we provide micro evidence that the stock of talent on the basis of both management and employees is essential for the improvement of corporate innovation, productivity, and shareholder value, while prior studies primarily investigate the effect of human capital from the macro perspective.

This paper also adds to the literature on the impact of environmental pollution. Prior studies of the impact of air pollution, other than health outcomes, have focused on the labor supply of households (Hanna and Oliva, 2015), labor productivity (Graff Zivin and Neidell, 2012; Chang *et al.*, 2016), and investor trading behavior (Li *et al.*, 2017). However, the impact of air pollution on corporate decision makers and key employees of listed firms are unknown. Understanding this effect is important given the significance of economic outputs by the publicly listed firms.

Our study also has significant policy implications. China, as well as many other countries, are facing a challenge to sustain their economic growth due to rising labor costs and weak external demand (Wei *et al.*, 2017). The most plausible solution, as suggested by Wei *et al.* (2017), is innovation and upgrading, with a specific tactic of attracting and retaining talent and skilled labor, for example, increase regional attractiveness by improving living amenity.[1] Nevertheless, regulators are reluctant to strengthen environmental regulations for fear of hurting firms' competitiveness and economic growth. This was evident at the 2009 United Nations Climate Conference where China and many developing countries refused to commit to mandatory emissions reduction targets.[2] A key source of the contention is to what extent air pollution affects

[1] Quality of life is the main criterial used by the IMD World Competitiveness Center to assess the competitiveness of talent of a region. Some countries, such as Singapore, have taken extensive initiatives to boost their status as an attractive place to live and work. Singapore has beat its rival Hong Kong in Asian Competitiveness report for consecutive years recently, with the former one having the strength in the issues of air quality and environment.

[2] "The UN Climate Change Conference, 2009 (COP 15)", ACCA, August 2009. Available at: https://research-repository.st-andrews.ac.uk/bitstream/handle/10023/3767/ACCA-2009-UN-Climate-Change.pdf?sequence=1&isAllowed=y

an economy's competitiveness. This study documents the accumulation of human capital is an important channel through which environmental regulation may benefit an economy.

2. Research background

2.1. The impact and determinant of human capital

The role of human capital in economic growth has received constant interest among economist and social scientists. The concentration of talent and skilled workers in a particular place reduces the costs of transmitting knowledge and sharing information, which leads to the "diffusion and growth of knowledge" (Jovanovic and Rob, 1989). The accumulation of human capital generates positive externalities that enhance productivity and growth (Lucas, 1988). As a result, the economic growth in a region crucially depends on its ability to attract and retain "brain". A large body of literature has documented that high levels of human capital (e.g., those with higher levels of education and work experience) are associated as with high regional income and productivity (Rauch, 1993; Black and Lynch, 1996). In particular, Gennaioli *et al.* (2013) study the determinants of regional development using a large dataset of 110 countries and accounting for various influential factors such as geography, natural resources, institutions, human capital, and culture. They find that worker and entrepreneurial education emerges as the most consistently important determinant of regional income and productivity.

While human capital plays a vital role in regional development, few studies have looked at the accumulation of executive talent and employees on corporate outcomes, probably due to the difficulty of measuring corporate human capital. Using demographic and firm information from the U.S. Census Bureau, Haltiwanger *et al.* (1999) find that firm productivity is significantly higher when there are a higher fraction of more-educated workers, which is consistent with the human capital model that more-skilled workers make the firm more productive. Ashraf and Ray (2017) use the reeducation in the quota of H-1B petitions as a shock to the skilled immigrant workers and find that firm-level innovation outcomes decline for immigrant-dependent firms in the post-period of the policy. Consistent with this study, Kerr and Lincoln (2010) find that more H-1B admissions increase the employment of science and engineering workers and the innovation by Chinese and Indian investors in cities dependent on the program. Literature on employee incentives (Chang *et al.*, 2015), employee age (Ouimet and Zarutskie, 2014), tolerance for failure (Tian and Wang, 2014), and labor law and unionization (Acharya *et al.*, 2013; Bradley *et al.*, 2017) also highlight the importance of employee human capital for corporate performance.

Recent studies have started to look at the impact of managerial human capital on corporate performance using managers' characteristics extracted from their resume. For example, Chemmanur *et al.* (2018) construct an index based on the top management's education and past experience. They find that higher quality managers are able to select better projects and thus have superior operating performance and consequent firm value and stock returns. Using the same managerial quality index, Chemmanur *et al.* (2019) find that higher quality managers have better foresight into the potential value of innovation opportunities and create a failure-tolerance environment that attracts skilled workers. In line with this view, Custódio *et al.* (2017) find that CEOs with general skills face better external job opportunities and thus have a greater tolerance for failure. Moreover, CEOs with skills transferable across firms and industries help to create a firm without boundaries that is beneficial for knowledge transfer (Custódio *et al.*, 2017).

Notwithstanding human capital for firm workers and managers may influence firm production functions differently, both of them are suggested to be key factors that drive the economic performance of a firm (Gennaioli *et al.*, 2013). Given the substantial influence, it is important to understand the factors that affect the accumulation of corporate human capital. Previous studies suggest that the accumulation of human capital is associated with IT facilities adoption and organization change (Bresnahan *et al.*, 2002), financial deregulation (Philippon and Reshef, 2012), local productivity change (Diamond, 2016), and local wages and land rents (Rauch, 1993). However, the impact of non-economic factors is under-investigated.

2.2. The impact of air pollution

Air pollution imposes high health risk on the human. Medical studies have shown that air pollution can cause numerous health problems such as respiratory and cardiovascular illnesses (Seaton *et al.*, 1995), heart disease (Dominici *et al.*, 2006), stroke (Hong *et al.*, 2002), and lung cancer (Kabir *et al.*, 2007). Recent studies find that air pollution may increase infant mortality (Tanaka, 2015) and reduce life expectancy (Chen *et al.*, 2013). Moreover, air pollutants such as particulate matter can be absorbed into the bloodstream and travel into the central nervous system, eventually causing cerebrovascular damage (Genc *et al.*, 2012). Exposure to air pollution can damage brain function and reduce individuals' cognitive skills (Lavy *et al.*, 2014).

Given the high environmental risk of air pollution to human health, people who place a high value on environmental quality (e.g., the high net wealth executives and skilled labor) have the incentive to flee from polluted places. This intuition is built on the perhaps the most popular and influential model of individual locating sorting, initially developed by Tiebout's (1956). The model suggests that people "vote with their feet" to find their community that provides an optimal bundle of public goods. In line with this theory, Banzhaf and Walsh (2008) find that air pollution causes individuals to leave for cleaner neighborhoods. Sullivan (2016) finds that better-educated people reside in places with better air quality, leaving the polluted areas becoming poor over time. This residential sorting effect is capitalized in the housing market — housing price increases when the air in a region becomes cleaner (Chay and Greenstone, 2005).

A growing literature has examined the impact of air pollution beyond traditional health outcomes ranging from labor supply and productivity to cognition. Air pollution may cause illness and lead to reduced work supply and productivity (Hanna and Oliva, 2015; Chang *et al.*, 2016). For example, Hanna and Oliva (2015) find that the exogenous reduction in sulfur dioxide resulting from the closure of a large oil refinery in Mexico City led to an increase in work hours. Graff Zivin and Neidell (2012) find that the concentration of ozone is negatively related to the productivity of farm workers. A recent study of call-center workers in China finds that higher levels of air pollution increase the time spent on breaks and reduce the total number of calls in a day (Chang *et al.*, 2016). Furthermore, air pollution is found to hurt investors' mental acuity and eventually reduce trading performance (Huang *et al.*, 2017; Li *et al.*, 2017). However, there is no systematic evidence to date on the impact on listed firms' decision makers and key employees and consequently their performance.

2.3. Air pollution in China and the Huai River policy

2.3.1. Air pollution in China

The rapid economic growth of China in the past three decades has lifted more than 600 million people out of poverty. However, great economic achievement comes at the expense of environment pollution. The particulate matter concentration in China is seven times the level in the US and is also higher the level in India (Greenstone and Hanna, 2014). A recent Green paper published by the Chinese Academy of Social Sciences indicates that the problem of haze and fog in China was hitting a record level and it is currently facing the worst air pollution problem since 1961. The problem of haze in China began to rise rapidly since the beginning of this century (Gao, 2008). A study of 1701 monitoring stations in China shows that the annual average number of haze days increases from 6 in 2000 to 18 in 2012 (Han *et al.*, 2016). More than 92% of residents in China have been exposed to PM2.5 concentration exceeding 10 μg/m3 since 2000. This exposure rate increased to 98% in 2012. During the same time, western countries such as the UK and US have experienced a significant decline to a level below 20% (Hsu *et al.*, 2014).

In particular, from 2012, the regular occurring haze weather in the winter and spring began to draw extensive public attention. Many cities especially those in the north have experienced very serious haze. In December 2013, China suffered a severe bout of air pollution with thick haze stretched from Beijing to Shanghai for a long distance of 750 miles. The level of PM2.5 in Beijing peaked at 35 times the World Health Organization's (WHO) recommended limit and were stuck at tremendous levels for weeks (Zhang *et al.*, 2014). Residents were seen wearing face masks; schools and airport were closed; kids were kept indoors; citizens in admissions for respiratory problems increased, and social networks exploded with complaints about the heavy blanket of smog. The terrible air pollution is making exodus of expatriates fleeing China.[3] One example is Hugo Barra, the vice-president of international at Chinese smartphone manufacturer Xiaomi, who announced to leave Xiaomi in early 2017. He said, "the last few years of living in such a singular environment have taken a huge toll on my life and started affected my health".[4] Many companies complain that it is harder to recruit outside talent in northern cities like Beijing.[5] Executive recruitment firms also state that it is getting harder to attract top talent to China, including both expats and Chinese nationals educated abroad.[6] The availability of computer or smartphone allows anyone to match their data with the choking clouds in front of them. It is reported that the strategies for leaving Beijing have become a hot topic on Weibo (China' Twitter).[7]

Coal consumption is considered to be a significant source of air pollution. According to the data from the U.S. Energy Information Administration. Coal consumption in China accounts for

[3] See "Why leave job in Beijing? To Breathe", April 14, 2013. Available at: https://www.wsj.com/articles/SB10001424127887324010704578418343148947824

[4] "Ex-Android executive quits Chinese smartphone maker Xiaomi", Financial Times, January 23, 2017. Available at: https://www.ft.com/content/2d8be270-e148-11e6-8405-9e5580d6e5fb

[5] "Airpocalypse' drives expats out of Beijing", Financial Times, April 1, 2013. Available at: https://www.ft.com/content/46d11e30-99e9-11e2-83ca-00144feabdc0

[6] See, "Execs Fleeing China because of bad air", CBS News, January 29, 2013. Available at: https://www.cbsnews.com/news/execs-fleeing-china-because-of-bad-air/ .

[7] "Smog dents Beijing's expat appeal", Financial Times, April 5, 2013. Available at: https://www.ft.com/content/b29afeae-9dc9-11e2-bea1-00144feabdc0

approximate 70% of the country's total fuel consumption since the 1980s. China is by far the largest coal consumer, accounting for 49% of global coal consumption in 2012. Coal and coal gas are the primary sources for the central heating system. During each winter, cities in northern China gradually activate their central heating systems. Together with the specific climate conditions, the increasing pollutants from fossil fuel combustion of the central heating systems intensify the haze in northern China. For example, in 2013, the central heating system was activated on November 15 in Beijing, Tianjin, Jinan, and Shijiazhuang, and on November 31 in Taiyuan. Just after that, a serious haze occurred and lasted for more than one week at the beginning of December in Beijing and northern China.

2.3.2. The Huai River policy

China's central heating policy, namely, the Huai River policy, was established to provide winter heating in northern China during the central planning period from the 1950s to 1980s. When initiating the policy, the Chinese government arbitrarily divided the territory into North and South China by the line formed by the Qinling Mountains and Huai River, which follows the January 0 ℃ average temperature line (see Figure 1). Free heating was provided to cities in the north of the line. The reason to choose this divide was that the Chinese government faced a budget constraint and was not able to supply free heating to all of China. In 2003, China issued a heat reform in the northern cities by changing the free provision system to a subsidized central-heating system. However, the way winter heating provided remains the same after this reform, and the supply is still only for northern China.

The centralized heating system rests on the use of coal-based hot water boilers, which is inflexible and energy inefficient. Hot water needs to travel a certain distance from the heating provider to each household in a city, causing substantial energy loss. The incomplete combustion of coal in the boilers releases a significant amount of air pollutants, especially particulate matter, which leads to haze. It also leads to the release of total suspended particulates (TSP), SO_2, and NO_2. Almond *et al.* (2009) find that the Huai River policy has led to a discontinuous higher level of TSP on the north side of the policy. Using this discontinuous change in air quality, Chen *et al.* (2013) find that people living to the north of the heating boundary, on average, have 5.5 years shorter life expectancy than those to the south.

3. Data, variables, and empirical strategy

Our sample covers all firms publicly listed on China's two stock exchanges (Shanghai Stock Exchange and Shenzhen Stock Exchange) over the period from 2000 to 2016. We start with the year 2000 because the Chinese Ministry of Environmental Protection (MEP) released the daily air quality index (AQI) since 2000.

To construct human capital measures, we collect the background information of top executives (CEO and board chairman) from China Corporate Figure Characteristics Series database (GTA_TMT) in China Stock Market and Accounting Research (CSMAR). For those with missing information, we manually search the executives' information on the firms' annual report, company website, and other online sources (e.g., Google and Baidu search). We collect the information on employee composition from the Wind Financial Database (WIND). Chinese listed firms started to disclose the employee structure information since 2011. Thus, for the analysis of employee human capital, we reduce our sample to the period from 2011 to 2016. Firms' location information (e.g., provinces and cities where firms headquarter) and financial information are also collected from the CSMAR database. The patent information is gathered from the China Listed Firm's Patent and R&D Innovation database (GTA_LCPT) in CSMAR, with the original source coming from the State Intellectual Property Office of China (SIPO). Regional information including macroeconomic statistics and air quality index (AQI) is obtained from the National Bureau of Statistics of China (NBS) and China Regional Economic Research Database (GTA_CRE) in CSMAR. After merging the datasets and excluding missing observations, we eventually get 3,221 unique firms and have 31,647 firm-years observations from 2000 to 2016.

3.1. Measuring human capital

We measure the corporate human capital of both top management and firm employees. We gauge top management human capital by assessing whether the CEO or chairman was born or obtained college degrees outside the location where their firm domiciles, or had work or study experience overseas. Specifically, we define:

Non-locally born executives: A dummy, which equals 1 if the CEO or chairman was born in a region outside the province where the firm is domiciled and 0 otherwise.

Non-locally educated executives: A dummy, which equals 1 if the CEO or chairman got a degree from a university or college in a region outside the province where the firm is domiciled and 0 otherwise.

Executives with overseas experience: A dummy, which equals 1 if the CEO or chairman has a study or working experience abroad and 0 otherwise.

We measure a firm's employee human capital based on the composition of employees by education and job functions. Specifically, we define:

% of high education employees: The number of employees with a bachelor degree or above, scaled by the total number of employees.

% of low education employees: The number of employees whose highest education level is high school or below, scaled by the total number of employees.

% of skilled employees: The number of technical employees, scaled by the total number of employees.

% of production and sales employees: The number of production and sales employees, scaled by the total number of employees.

% of financial and administrative employees: The number of financial, HR, administrative employees, scaled by the total number of employees.

The human capital variables are filled with a missing value if no information is observed from the database. Please note, the sum of *% of high education employees* and *% of low education employees* is not 100% since employees in the middle level of education such as those having non-bachelor degrees are also included. The sum of the employee percentage by job function is also not 100% since some employees are not classified by the job functions.

3.2. Measuring firm performance

To assess the consequence of brain drain induced by air pollution, we focus on firm performance on the basis of innovation and productivity, and also firm valuation and operating performance. We measure corporate innovation using the number of patents filed by a company, which is widely accepted as the primary measure of innovation in the literature (e.g. Lerner *et al.*, 2011; Hirshleifer *et al.*, 2012). According to the Chinese Patent Law, Chinese patents are categorized into three groups—invention patents, utility model patents, and design patents. Invention patents are granted for technological solutions. Utility model patents are for new functions of products. Design patents are granted for new "look" designs of products. Following Tan *et al.* (2015), we focus on the first two types of patents to measure a firm's innovation output, because design patents involve limited technological advancement. To better identify the effect related to air pollution in a firm's location, we use the counts of firm patent applications in the region where the firm headquarters. We further scale the counts of patents by the number of firm employees (see, Cohen *et al.*, 2013; Hirshleifer *et al.*, 2013). Specifically, our first measure is *Inventions/employees*, which is log (1+ the number of invention patent applications in the region where the firm headquarters, scaled by employees (in thousand)). The second measure is *Utility models/employees*, which is log (1+ the number of utility model patent applications in the region where the firm headquarters, scaled by employees (in thousand)). We also alternatively define the innovations using the log of patent counts and the log of patent counts scaled by R&D for robust analysis.

We estimate firms' total factor productivity (*TFP*) using the methodology developed by Levinsohn and Petrin (2003) where the output is the firm's net profits (net value added), firm's labor is the number of employees, and firm capital is property, plant, and equipment (PPE). We measure firms' value and operating performance using Q, which is defined as the market value of total equity over book value of total equity, and *sales growth*, which is defined as the annual growth rate to total sales.

3.3. Explanatory variables

A firm is treated if it locates in a city where the central heating system operates. Specifically, we create a variable *North*, which takes the value of 1 if the latitude distance between a firm's located city and the line of Qinling-Huai River (the former - the latter) is positive and 0 otherwise.

To measure the level of air pollution, we use the air quality index (AQI) published by the MEP. The AQI synchronizes various types of air pollution, including SO_2, NO_2, PM_{10} (suspended particulates with a diameter of 10 μm or less), $PM_{2.5}$ (suspended particulates with a diameter of 2.5 μm or less), CO, and O_3. A higher AQI level means a higher level of air pollution. Air quality is considered to be good for AQI below 100. An AQI above 100 indicates pollution. To merge with other variables, we create a variable *AQI* by aggregating the daily index using the average of daily *AQI* in the winter months (Oct, Nov, Dec, Jan, Feb, and Mar). Figure 2 shows the average *AQI* of cities from 2000 to 2016. We find that the north side of the central heating border has a higher level of *AQI* than the south side, with the difference ranging from about 10 to as much as 30. We also find that Chinese air pollution, starting in 2012, soars in recent year.

We control for firm characteristics that may affect firms' demand for human capital (Hirshleifer *et al.*, 2012; Bradley *et al.*, 2017). They include *Firm size* (log(total assets)), *Leverage* (total liability/total assets), *Cash flow* (operating income before depreciation and amortization/total assets), *Capital expenditures* (Capex/total assets), *Firm age*, *Executive age* (average age of CEO and board chairman), and *SOEs* (state-owned enterprises indicator) We also control for regional characteristics that may relate to a region's employment opportunities and human capital supply, which include *GDP growth*, *GDP per capita*, *Education expenditures* (government expenditures in education/total government expenditures), and *Population density* (log(number of population per square kilometer)), Finally, we also control for average monthly temperature in a region (*Temperature*) as recent literature suggests that temperature has an impact on human's mental health (Chen *et al.*, 2018). Appendix I provides the definition, data source, periods for all variables.

3.4. Descriptive statistics

The summary statistics for the key variables used in this study are reported in Table I. The mean of *North* is 36%, indicating there are more firms located in the north. In our robustness checks, we exclude the metropolises (i.e., Beijing, Shanghai, Guangzhou, and Shenzhen) and focus on firms headquartered in regions within a small margin along the heating border. We also find that 36% (50%) of firms have a CEO or chairman born (obtained college degrees) outside the provinces they locate, and 9% of CEOs or chairmen have foreign experience. Regard to employee structure, 26% of employees have degrees of bachelor or above and 19% of employees are equipped with technical skills.

[Insert Table II about here]

3.5. RDD and diagnostic test

To examine the effects of air pollution on human capital and firm performance, the conventional approach is to estimate the following model using the ordinary least squares (OLS) in a firm-year panel.

$$y_{i,t+1} = \alpha + \beta AQI_c + X_{i,t} + u_{i,t} \quad (1)$$

where *i* indexes firm, *t* indexes year, and *c* indexes the city where the firm is located. The dependent variable (y) is measures of human capital and firm performance. *X* is a vector of the observable firm and regional characteristics. However, a concern with this regression is that the *AQI* may be correlated with unobservable firm characteristics and regional factors that may also influence the firms' human capital and performance, in which case the omitted variable bias emerges and the estimate of β cannot be interpreted as a causal effect of air pollution. To deal with the identification problem, we use a regression discontinuity design (RDD) that exploits the discontinuous variation in air pollution created by the Huai River policy.

Precisely, we strictly follow Almond *et al.* (2009) and Chen *et al.* (2013) and estimate the following reduced form regression.

$$y_{i,t+1} = \alpha + \beta North_c + f(Lat_c) + X_{i,t} + T_t + I_j + L_c + u_{i,t} \quad (2)$$

where *North* is the notation indicating whether a firm is located in the north of the Qinling-Huai River border. $f(Lat_c)$ are smooth control functions for latitude, allowing for a different polynomial for observations to the heating boundary. We further control for year fixed effects (vector *T*) and industry fixed effects (vector *I, j* indexes industry). To reduce the scope of unobserved factors on either side of the heating border spanning from the west to the east, we also include the fixed effects of longitude decile (vector *L*). A negative estimated β would indicate that firms located in more polluted regions have a lower level of human capital accumulation and performance.

This design can also be used to develop the following two-stage least squares (2SLS) to estimate the impact of *AQI* on corporate human capital.

$$AQI_{c,t} = \gamma_0 + \gamma_1 North_c + f(Lat_c) + X_{i,t} + Y_t + I_j + L_c + u_{i,t} \quad (3.1)$$

$$y_{i,t+1} = \theta_0 + \theta_1 \widehat{AQI}_{c,t} + f(Lat_c) + X_{i,t} + Y_t + I_j + L_c + u_{i,t} \quad (3.2)$$

Specifically, if the Huai River policy influences corporate human capital through its impact on *AQI*, it is valid to run equation (3.1) to obtain the variation of *AQI* caused by the policy and then relate the fitted values of *AQI* to human capital outcomes using Equation (3.2). An important appeal of the 2SLS approach is that it produces estimated units of the impact of *AQI* on corporate human capital and firm performance.

A valid RDD requires that 1) the heating policy causes the change of assignment in pollution 2) the assignment *per se* is independent of firm outcomes. To assess the first condition, we first plot out the average *AQI* from 2000 to 216 in each China's region. As shown in Figure 1, we find the areas with *AQI* above 100 (shaded in red) and the areas with *AQI* below 100 (shared in green) are well partitioned by the Qinling-Huai River boundary, suggesting a significant difference in air pollution at the central heating border. We further make the regression discontinuity plots of *AQI* in Figure 3. We find that the level of *AQI* in the north is about 20 units (or 25%) higher than the level in the south at the boundary. The results suggest that the arbitrary heating policy indeed causes a discontinuous change in ambient air pollution.

[Insert Table II about here]

To verify the second condition, we examine whether there is a discontinuity in other covariates that are correlated with corporate human capital and performance at the boundary. In Panel A of Table II, we present the differences in firm and regional characteristics between the two sides of the heating border by a small margin (2 degrees around the Qinling-Huai River). We find that most of the characteristics have insignificant differences between the two sides. Moreover, we test the differences in expected firm human capital and performance between the two sides. Specifically, we regress human capital and performance variables on all firm and regional covariates. The fitted valued obtained from the regressions are our measure of expected human capital and performance. We find that, as shown in Panel B, the expected firm outcomes are insignificantly distinctive for firms in the South and North. Overall, the diagnostic tests suggest that the determinants of outcome are independent of the treatment assignment.

4. Air pollution and corporate human capital

Before reporting the regression estimates, we provide a visualization of the human capital difference of firms across the central heating border. The results are presented in Figure 4 where the average of human capital of all firms in a region is plotted on the region's latitude distance from the heating border. Panel A is the plot for the regional average of high-quality executives (i.e., the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*). Panel B is the plot for the regional average of high-quality employees (e.g., the average of *% of high education employees* and *% of skilled employees*). The regional averages are fitted using a linear line. The estimates with a 90% confidence interval around the fitted values are shaded. The x-axis is the latitude distance from the heating border. A positive (negative) degree distance means the firms located in the north (south) part of the border. From the figure, we find there is a discontinuous drop in high-quality executives and firm employees at the border (i.e., the latitude distance is 0). Moreover, the fitted line on the north side is below the shaded area of the estimates on the south side, suggesting that the drop is significant.

4.1. Air pollution and the accumulation of executive talent

The RDD estimates of the impact of air pollution on the corporate human capital of management are reported in Table III. Specifically, we estimate Equation (2) using a probit model where the dependent variables are *Non-locally born executives, Non-locally educated executives* and *Executives with overseas experience*. We control for firm and regional characteristics. We also include the year, industry and longitude fixed effect to control for potential unobservable factors. The key independent variable is *North,* which indicates firms located on the north side of the Qinling-Huai River border. We estimate the model with standard error estimated clustering at firm levels. From the table, we find that the coefficients on *North* are all negative and statistically significant for the three measures of executive talent. The results are consistent with the graphic plot of executive human capital in Figure 4 and suggest that air pollution indeed place a negative impact on the accumulation of executive talent. The impact is also economically significant. At the bottom of the columns, we report the marginal effect of the estimates, namely, the change of probability of having the skilled executive talent for firms located in the north that would have located in the south. The estimates suggest that locating in the north of the central heating border leads to a 21% decline in the probability of having a non-locally born executive, 14% decline in the probability of having a non-locally educated executive, and 7% decline in the probability of having an executive with overseas experience. The results suggest that firms headquartered in polluted areas are less likely to accumulate better quality of executive talent.

Turning to the control variables, we find that non-SOEs and firms in regions with high GDP growth are more likely to have a better quality of executives, indicating that talented executives are tempted to firms or regions with better growth opportunities. In addition, we find that executives from outside and having foreign experience tend to be young and they have more interest in large and young firms.

[Insert Table III]

4.2 Air pollution and the accumulation of high-quality employees

In Table IV, we present the results of RDD estimating the effects of air pollution on employee human capital. We measure firms' employee human capital based on the composition of employees by education and job functions. Panel A presents the estimates for employee human capital by education composition. Employees are considered to have a high (low) education level if they have a bachelor's degree or above (have the highest education level of high school or below). We calculate the composition of high (low) education employees by scaling the number of high (low) education employees by the total number of firm employees. In column 1, we find that the coefficient on the *North* is significantly negative when the dependent variable is *% of high education employees*. The result is economically significant. It suggests that the proportion of firm employees holding a bachelor's degree or above for firms in the north is 17% (i.e., 0.044/.26) lower than the proportion of an average firm in the south. However, in the model of *% of low education employees* (column 2), we find the coefficient on the *North* is insignificant and has an opposite sign. The results suggest that air pollution causes a decline in the composition of high-educated employees only.

Panel B reports the estimates for employee human capital by job functions. We classify the job functions of employees in three types: Skilled and technical employees, production and sales employees, and financial, HR, and other administrative employees. The number of these three types of employees is scaled by the total number of employees. From the table, we find that the coefficient on *North* in the model explaining the composition of technical employees is significantly negative while the coefficients in the models explaining the composition of the other two types of employees are insignificant. The estimate for the composition of technical employees has economic significance. It suggests that the proportion of technical or skilled employees in the north is 15% (i.e., 0.028/0.19) lower than the proportion in the south. Overall, the results indicate that air pollution reduces the accumulation of better-educated and skilled firm employees.

[Insert Table IV]

4.3 Robustness checks

We conduct additional tests to check the robustness of our findings. First, to more explicitly show that the decline of the human capital is directly related to air pollution, we estimate a 2SLS regression by relating the instrumented air quality to human capital measures. We use the *North* as the instrumental variable (IV) and estimate the fitted value of *AQI* using Equation (3.1). The fitted value of *AQI* is then regressed to the human capital variables using Equation (3.2). The results are reported in Table V. Columns with odd numbers report the results of the first stage regression. We find that areas north to the heating border actually have a significantly higher level of *AQI* than areas south to the border, resonating the discontinuity plots of *AQI* in Figure 3.

[Insert Figure 3 and Table V]

The estimates of the second stage are reported in columns with even numbers. Consistent with previous results, we find the fitted *AQI* is significantly and negatively associated with the measures of human capital. In Panel A, the quality of human capital is measured at the executive level. The results show that firms located in regions with a high level of pollution are less likely to have CEO or chairman that are non-locally born, non-locally educated, or have overseas experience. Panels B and C present the estimates for the employee compositions by education and job functions, respectively. We find that a high level of air pollution is associated with a low proportion of high-education employees and technical employees. However, there is no significant relationship between pollution and the proportion of low-educated and non-technical employees.

A potential concern is that our findings may be driven by unobservable regional factors that are related to air pollution and the accumulation of human capital simultaneously. For example, a better-developed region could have less air pollution and better employment opportunities. To mitigate the concern, we re-estimate our models by focusing on firms located in cities along the Qinling-Huai River border. We exploit the fact that unobservable factors such as economic conditions and social interaction effects are likely to be similar in neighboring regions, whereas air pollution has a sharp difference across the policy border. To conduct the test, we conduct local RDD by focusing on firms located in regions with a distance smaller than 2 degrees in latitude from the Qinling-Huai River. The estimated results are reported in Table VI.

[Insert Table VI]

Panel A presents the results for executive talent. We find that the coefficients on *North* are negative and highly significant, indicating firms located on the north side of the central heating border by a small margin are less likely to have CEOs or chairmen that were born or educated outside or had foreign experience than firms located on the north side of the border. Panels B and C presents the estimates for the human capital measures of employees. We find that the compositions of better educated and skilled employees are significantly lower on the north side of the heating border than those on the south side. Overall, we find consistent evidence on the detrimental effect of air pollution on the accumulation of corporate human capital.

4.4. Heterogeneity in the concern for amenity

So far, our findings show that there is a significant negative relation between air pollution and the accumulation of corporate human capital, which is consistent with Tiebout's location sorting model (1956). In this section, we substantiate this sorting argument by examining whether people's attention to or concern for amenity increases when air pollution arises. We further examine how the effects of air pollution on human capital vary with the regional heterogeneity in individuals' concern for amenity.

We measure people's attention to or concern for amenity using the Baidu Search Volume Index (SVI) in a region. Baidu SVI, similar to Google SVI, started to report the SVI of words that people commonly search online since 2011. We measure people's attention to health amenity using the Search Volume Index (SVI) of "health (健康)". We also measure people's willingness to flee due to the aversion to disamenity using the SVI of "quit job (辞职)". We collect the daily SVI of all cities from 2011 to 2016 and merge them with the daily air quality index (AQI). We then regress the change of SVI on the change of AQI. Specifically, we run the following models:

$$\%Change\ of\ Search\_Health_{c,t+1} = beta_1 * \%Change\ of\ AQI_{c,t} + Control + e_{c,t+1}$$

$$\%Change\ of\ Search\_JobQuit_{c,t+1} = beta_2 * \%Change\ of\ AQI_{c,t} + Control + e_{c,t+1}$$

where $\%Change\ of\ Search\_Health_{c,t+1}$($\%Change\ of\ Search\_JobQuit_{c,t+1}$) is the percentage change of daily SVI by the word of "health (健康)" ("quit job (辞职)") in city *c* on day *t+1*; $\%Change\ of\ AQI_{c,t}$ is the percentage change of AQI in city *c* on day *t*. We also control for regional characteristics and year fixed effects. A positive $beta_1$ indicates that people's attention to health significantly increases upon the rise of air pollution. A positive $beta_2$ indicates that people have an aversion to bad air and the tendency to quit current job and flee from the polluted place.

The estimates of the region-date panel regression are reported in Table VII. Standard errors are estimated by clustering at two ways of city and date levels. We find that the coefficient on $\%Change\ of\ AQI_{c,t}$ in columns 1 and 3 are positive, significant at the 1% level. The results suggest that an increase in air pollution is associated with a subsequent increase in public concern for health and willingness to fleet. The results are similar after controlling for regional characteristics, as shown in columns 2 and 4.

[Insert Table VII]

Given the evidence that air pollution raises people's concern for life amenity, we further examine how the heterogeneity in individuals' preferences for amenity affects the effects of air pollution on corporate human capital. Based on Tiebout's location sorting model (1956), individuals have heterogeneous preferences for public goods and sort into locations that best match their preferences. If the air pollution affects corporate human capital via affecting people's life amenity, we expect that our findings on corporate human capital will become stronger in regions where people's concern for amenity is more sensitive to the air pollution. To test this conjecture, we estimate a sensitivity of daily SVI of "health (健康)" to the change of daily AQI by running time-series regressions for each city in each year. The estimate is notated by *Health-pollution sensitivity*. Similarly, we estimate a sensitivity of daily SVI of "quit job (辞职)" to the change of daily AQI, notated by *Job quit-pollution sensitivity*. We then re-estimate our baseline models (Equation (2)) by augmenting the regional-level sensitivity measures and their interaction with *North*.

The results are reported in Table VIII. Panel A presents the estimates for *Health-pollution sensitivity*. We find that the coefficients on *North* in the models of non-locally born management (column 1), non-locally educated management (column 2), high-educated employees (column 4), and skilled employees (column 6), becomes more negative and significant when the *Health-pollution sensitivity* is higher. Similar to the previous result, we find the interaction effects do not show up in the models of low-educated employees (column 5) and non-technical employees (columns 7 and 8). We find a similar pattern, as shown in Panel B when *Job quit-pollution sensitivity* is used. Overall, the results show that the negative relationship between air pollution and corporate human capital concentrates on regions where people's concern for amenity is more sensitive to air pollution, confirming our argument that that air pollution raises people concerns for health and eventually affects the human capital of local firms.

[Insert Table VIII]

4.5. Regional evidence of brain drains

We further examine whether air pollution has an impact on human capital accumulation using regional migration information. We collect regional migration information from the 2000 and 2010 PRC population census. The census data provides the number migrants (i.e., those who are living in a province but their household registration place is in other provinces.) by job functions and education in each China' province. We create variables to measure the composition of migrants by job functions, including *Skilled migrants* defined as the number of skilled and technical migrants/total population in a region, and *Non-skilled migrants* defined as (the number of total migrants- the number of skilled and technical migrants)/total population in a region. We also create variables to measure the composition of migrants by education, including *High education migrants* defined as the number of migrants with bachelor degree or above/total population in a region, and *Low education migrants* defined as the number of migrants whose highest education level is high school or below/total population in a region. We merge the migration composition variables with *North* and other city-level variables. We estimate the RDD as in Equation (2) using the city-year panel data. The results are reported in Table IX. We find the cities in the north have a significantly lower level of skilled migrants and high education migrants. However, there is no significant difference in non-skilled migrants and low-education migrants between the north and south areas. The results confirm our previous findings that the effect of air pollution concentrates on skilled labor.

[Insert Table IX]

While the migration data is only available in 2000 and 2010, we complement the test using regional tourism information over the period from 2000 to 2015. We measure the attractiveness of a region using the number of foreign tourists scaled by the total population in that region in a year (*Tourists*). The RDD estimates are presented in column 5. As expected, we find that the north polluted areas are much less attractive to foreign tourists. Our findings thus suggest that air pollution not only drives people to leave but also dissuades others from coming.

5. Air pollution and firm performance

Thus far, we obtain robust evidence that air pollution has a negative effect on corporate human capital. Given the importance of human capital for corporate long-term growth and success, in this section, we examine whether air pollution has an impact on firms' performance and whether such impact arises through the channel of human capital.

5.1 Corporate innovation and productivity

Previous studies suggest that top management quality (e.g., education and past experience) and employee skills are important determinants of corporate innovation (Ashraf and Ray, 2017; Chemmanur *et al.*, 2019), and corporate productivity (Haltiwanger *et al.*, 1999). To the extent that air pollution hurts corporate human capital, we expect that air pollution would impede corporate innovation and productivity. We conduct the test in this sub-section.

We measure corporate innovation using the counts of a firm's patent applications in the region where it headquarters, scaled by its total employees (see, Cohen *et al.*, 2013; Hirshleifer *et al.*, 2013), notated by *Inventions/employees* and *Utility models/employees*. We estimate a firm's productivity using total factor productivity (*TFP*) as in Levinsohn and Petrin (2003). Appendix I provides a detailed definition of the variables. In Figure 5, we make the regression discontinuity plots of the measures. Indeed, we find that there is a discontinuous reduction in corporate innovation and productivity at the central heating border (i.e., degree 0). We then do a comprehensive analysis by re-estimating Equation (2) using the innovation and productivity measures as the dependent variable. The results are reported in Panel A of Table X.

We find that the coefficients on *North* are negative and highly significant, suggesting air pollution indeed impedes corporate innovation and productivity. Specifically, these estimates suggest that locating in the north of the heating border leads to a 0.28 (i.e., $e^{-0.331} - 1$) decline in the number of invention patents per thousand employees and a 0.33 (i.e., $e^{-0.395} - 1$) decline in the number of utility model patents per thousand employees. It also suggests that the *TFP* of firms in the north is likely to be lowered by around 27% (i.e., 0.03/0.11), compared to the average firms in the south. We alternatively measure corporate innovation using the log of patent counts (i.e., *Inventions* and *Utility models*) and patent counts scaled by R&D (i.e., *Inventions/R&D* and *Utility models/R&D*). To save space, we report the results in Appendix II. The results are highly robust.

[Insert Table X]

We also estimate the relation between air pollution and corporate innovation and productivity using the 2SLS. The results are reported in Panel B. We find the instrumented *AQI* is negatively and significantly related to the measures of corporate innovation and productivity. To address the concern of unobservable factors, we also re-estimate the local RDD using a small sample of firms that locate in regions within a 2-degree latitude distance from the central heating border. The results are reported in Panel C. We find the coefficients on *North* remain significantly negative. Overall, the results in this section show that firms located in the north polluted areas have lower corporate innovation and productivity than firms located in the south.

5.2 Firm value and sales growth

Considering the essential role of human capital for firm value creation and performance improvement (Chemmanur *et al.*, 2019), we complement our analysis by examining the impact of air pollution on firm value and operating performance. Firm value is measured by Tobin's Q, defined as the market value of total equity over book value of total equity (*Q*). Operating performance is measured by the annual growth rate of total sales (*Sales growth*). In Figure 6, we make the regression discontinuity plots of the *Q* and *Sales growth*. The figure shows that there is a drop in firm value and sale growth at the central heating border (i.e., degree 0). The RDD estimates results are reported in Panel A of Table XI.

[Insert Table XI]

From the panel, we find that firms located in polluted regions are significantly associated with lower firm value and sales growth. Specifically, firms located in the north of the heating border have 25% (i.e., -0.682/2.76) lower in Tobin's Q and 51.2% (i.e., -0.128/0.25) lower in sales growth than the average firms located in the south. Panel B reports the 2SLS results using the *North* as the instrumental variable. The results largely mirror those in Panel A. Panel C report the local RDD estimates. While the effects become weaker, the estimates are still significantly negative, indicating that our results may not be driven by confounding regional factors.

5.3 Firm performance and human capital dependence

Lastly, we examine whether the negative relation between air pollution and firm performance is mediated by corporate human capital. If air pollution harms firm performance through hurting the accumulation of corporate human capital, the effects of air pollution on firm performance should be more pronounced in firms in which their performance depends on human capital more.

To measure firms' human capital dependence, we regress each of the firm performance measures (*Inventions/employees*, *Utility models/employees*, *TFP*, *Q*, and *Sales Growth*) on the human capital of management (the average of *Non-locally born executives*, *Non-locally educated executives*, and *Executives with overseas experience*) and the human capital of employees (the average of *% of high education employees* and *% of skilled employees*), respectively. We run the regressions within each industry in each year using data over the past five years, with firm characteristics (i.e., *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls. The coefficients on the human capital variables are the measure of human capital dependence for each industry. They gauge the degree to which firm performance in an industry relies on skilled top managers and high-quality employees, with a great value indicating high dependence. We then re-estimate the models of firm performance by adding the human capital dependence measures and their interaction with *North*. The estimated results are reported in Table XII.

[Insert Table XII]

Panel A presents the estimates when the dependence on managerial human capital is used. We find the coefficients *North* remain significantly negative. Our focus is the coefficients on the interactions between the *North* and the human capital dependence measures. From the table, we find they are negative, with significant levels. The results indicate that the detrimental effect of air pollution on firm performance is particularly salient in industries with high dependence on managerial human capital. Panel B presents the estimates when the dependence on employee human capital is used. The results largely mirror those in Panel A and show the effects of air pollution on firm performance is more pronounced in firms that depend on employee human capital more. Overall, the results help to confirm that air pollution influences firm performance through the channel of human capital.

5.4. Regional evidence of performance

Finally, we examine whether air pollution has a general impact on regional innovation performance. We measure regional innovation using the total number of patent applications and new products issued by enterprises in a region. We collect the information from the database of China Regional Economic Research Database (GTA_CRE) in CSMAR, which provides information, including the number patent applications, the number of new product issuance, the total R&D expenditures, and the total number of R&D researchers in each provincial region since 2008. We measure a region's innovation using the number of patent applications in the region scaled by the total regional R&D expenditures (*Patents/R&D*), and scaled by the total number of R&D researchers (*Patents/R&D researchers*). We measure regional new product development using the number of new product issuance in a region scaled by the total regional R&D expenditures (*New products/R&D*), and scaled by the total number of R&D researchers (*New products/R&D researchers*). The RDD estimates are reported in Table XIII. We find that the coefficients on *North* in all models are negative and significant. The results suggest that the polluted areas are less likely to develop innovative patents and new products than the less polluted areas, which further confirms the detrimental effect of air pollution.

[Insert Table XIII]

6. Conclusion

In this paper, we use a unique regression discontinuity design created by the Huai River policy in China and examine whether air pollution exerts an adverse effect on the accumulation of corporate human capital and casts economic losses on publicly listed firms. Using corporate human capital data at both executive and employee levels, we find robust evidence that firms in air-polluted regions have greater difficulty in accumulating executive talent and high-quality employees than firms in clean regions. This brain drain effect is more pronounced in regions where people's concern for amenity is more sensitive to air pollution, consistent with Tiebout's sorting model that people vote with their feet.

In addition, we find that the brain drain effect of air pollution manifests in corporate performance. Specifically, firms located in polluted areas have lower corporate innovation, productivity, firm value, and sales growth than firms located in less polluted areas. Importantly, we find that this negative relationship between air pollution and corporate performance gets stronger in the industries that highly depend on human capital, suggesting that human capital is the channel through which air pollutions affects firm performance. Overall, we show that air pollution is a crucial non-economic factor that has a significant impact on corporate performance by influencing the accumulation of corporate human capital.

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Figure 1: Qinling-Huai River and Air Pollution by Regions in China

The blue line represents the line of the Qinling-Huai River. Areas with average *AQI* from 2000 to 2016 above (below) 100 is marked in red (green). The red dots represent cities where listed firms are domiciled.

Figure 2: Average AQI Over Time

The bars represent the average *AQI* by year China. The red-solid (green-dash) line represents the average *AQI* in the north (south) side of the Qinling-Huai River.

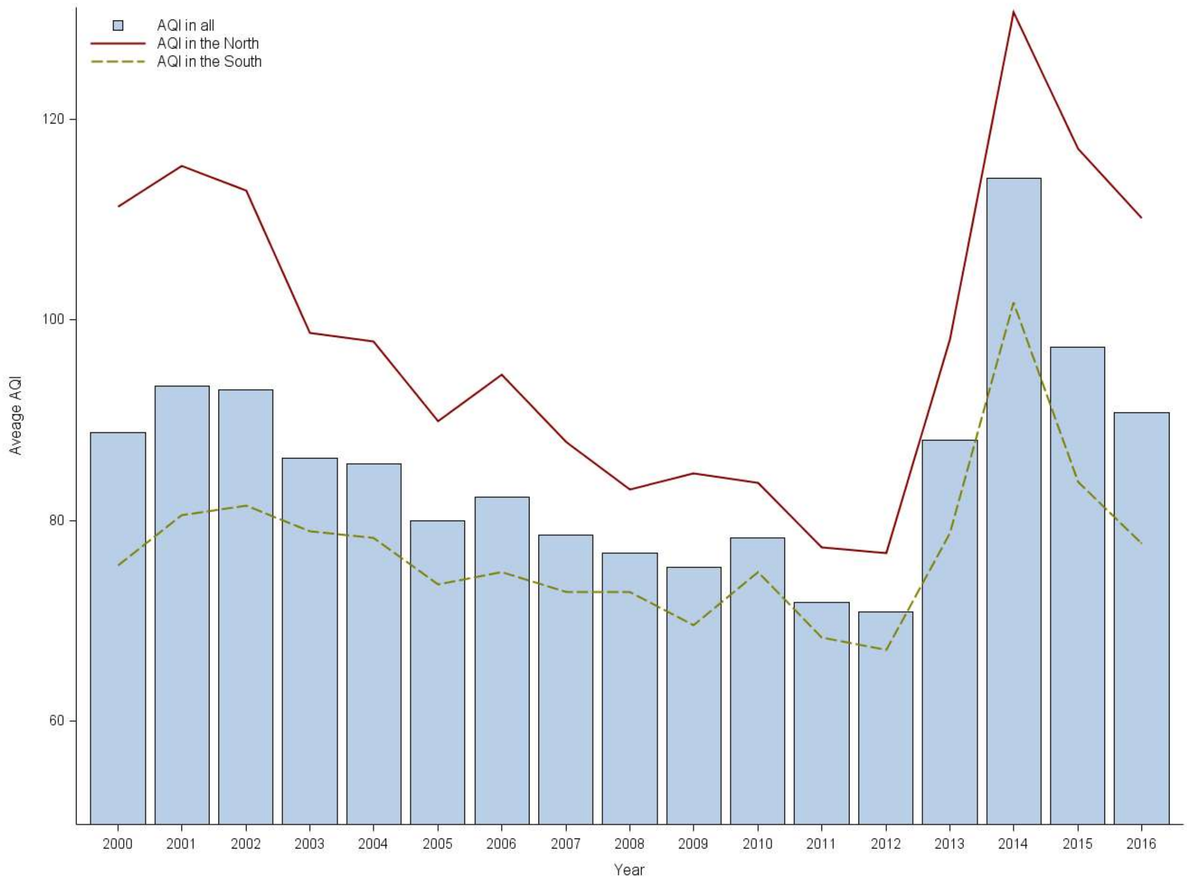


Figure 3: Regression Discontinuity Plots of AQI

The figures plot the Air Quality Index (AQI) across the Qinling-Huai River. Each dot is generated by averaging Air Quality Index (AQI) across locations within 0.1° of latitude (y-axis). The x-axis represents the latitude degree, with 0° indicating the latitude of the Qinling-Huai River and positive (negative) degrees indicating the north (south). The line presents the fitted values of AQI from a linear regression. The shaded area represents a 90% confidence interval around the fitted value.

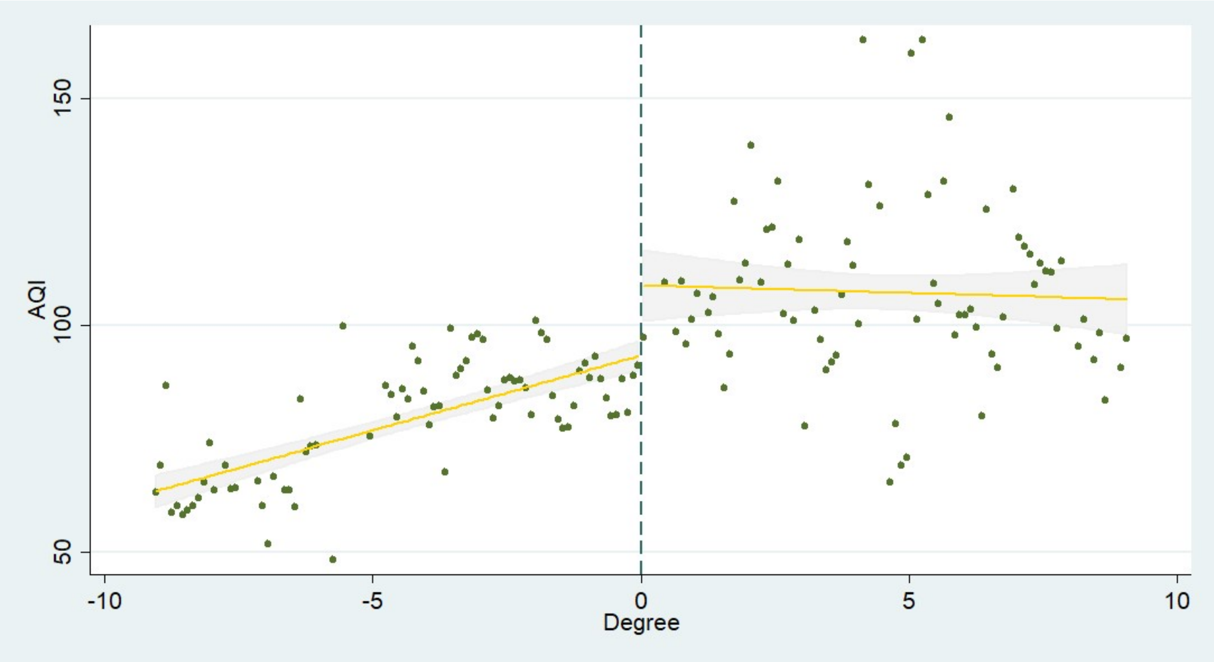
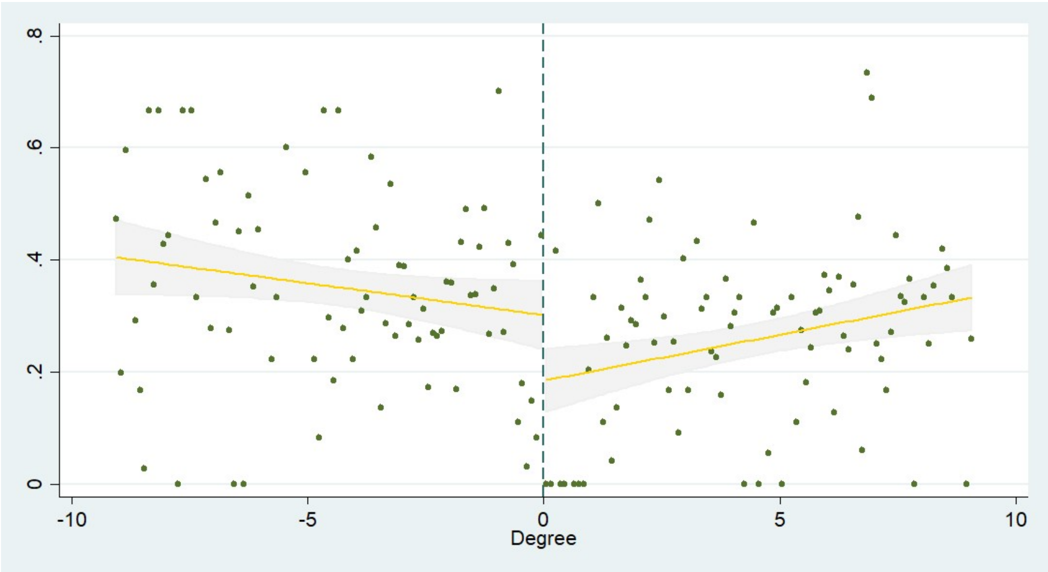


Figure 4: Regression Discontinuity Plots of Human Capital

The figures plot the human capital measures of firms across the Qinling-Huai River. Panel A plots average executive talents in a region, which is the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*. Panel B plots the average percentage of high-quality employees, which is the average of *% of high education employees* and *% of skilled employees*. Each dot is generated by averaging human capital measures of firms across locations within 0.1° of latitude (y-axis). The x-axis represents the latitude degree, with 0° indicating the latitude of the Qinling-Huai River and positive (negative) degrees indicating the north (south). The line presents the fitted values of human capital from a linear regression. The shaded area represents a 90% confidence interval around the fitted value.

Panel A: Executive talents



Panel B: % of High-quality employees

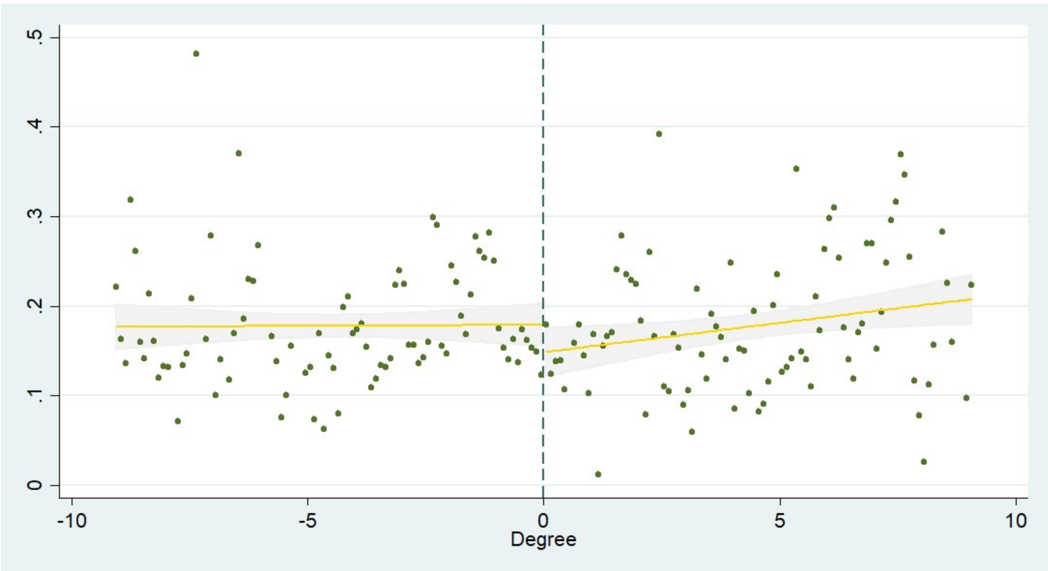
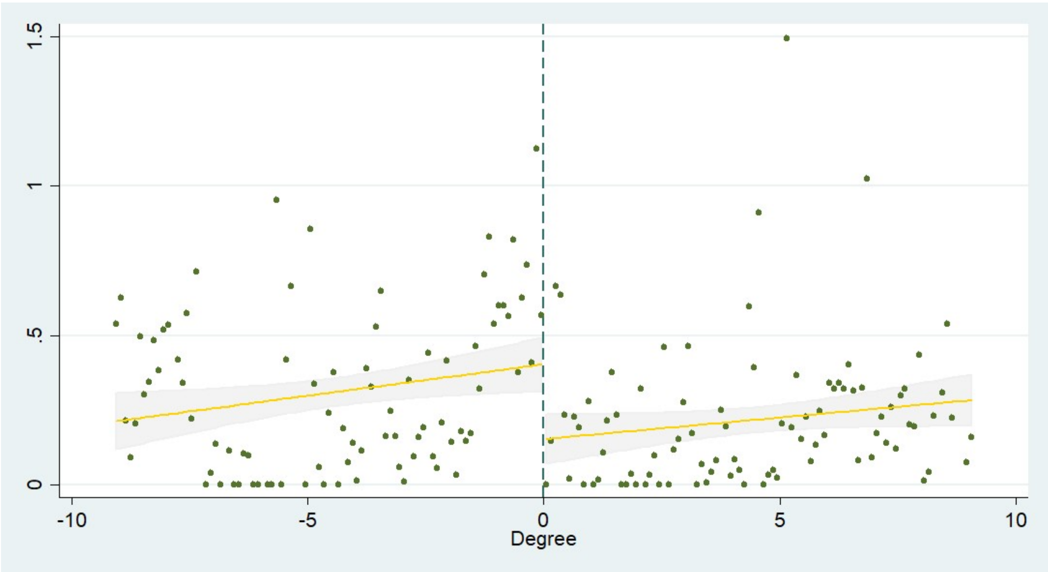


Figure 5: Regression Discontinuity Plots of Innovation and Productivity

The figures plot the innovation and productivity of firms across the Qinling-Huai River. Panel A plots average patents of firms in a region, which is the average of *Inventions/employees* and *Utility models/employees*. Panel B plots the average total factor productivity (*TFP*) of firms in a region. Each dot is generated by averaging outcomes of firms across locations within 0.1° of latitude (y-axis). The x-axis represents the latitude degree, with 0° indicating the latitude of the Qinling-Huai River and positive (negative) degrees indicating the north (south). The line presents the fitted values of outcomes from a linear regression. The shaded area represents a 90% confidence interval around the fitted value.

Panel A: Patents/employees



Panel B: Total factor productivity (*TFP*)

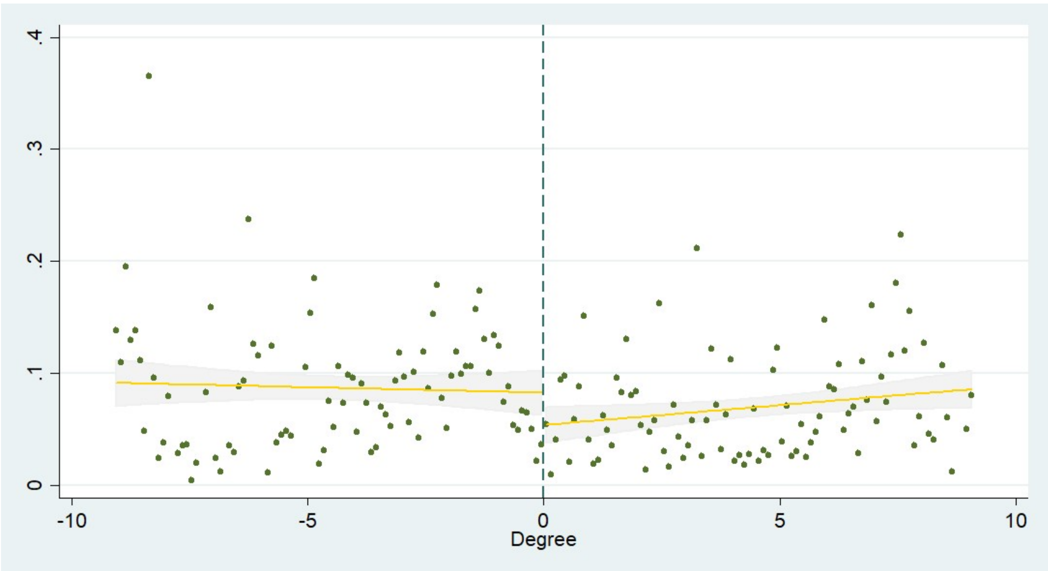
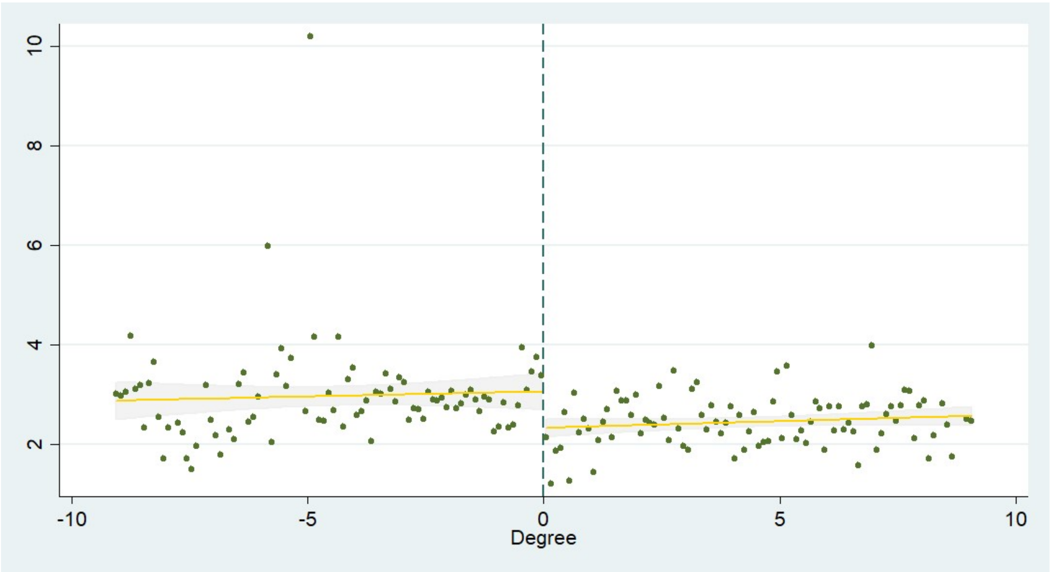


Figure 6: Regression Discontinuity Plots of Firm Value and Sales Growth

Panel A plots average firm value (*Q*) of firms in a region. Panel B plots the average total sales (*Sales growth*) of firms in a region. Each dot is generated by averaging outcomes of firms across locations within 0.1° of latitude (y-axis). The x-axis represents the latitude degree, with 0° indicating the latitude of the Qinling-Huai River and positive (negative) degrees indicating the north (south). The line presents the fitted values of outcomes from a linear regression. The shaded area represents a 90% confidence interval around the fitted value.

Panel A: Firm value (Q)



Panel B: Total sales growth (*Sales growth*)

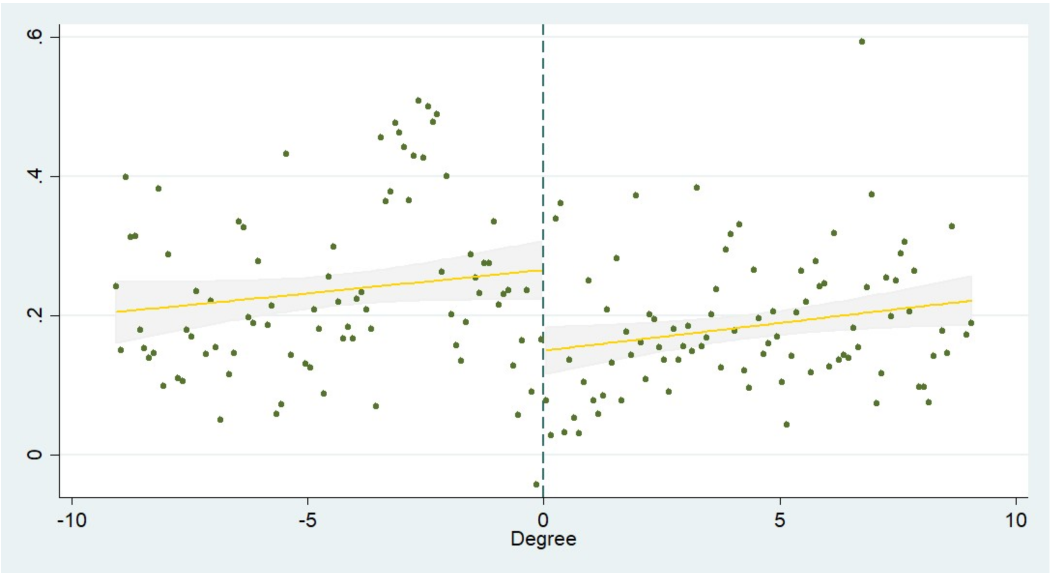


Table I
Variables Summary Statistics

This table reports the summary statistics of the main variables used in the study. All variables are defined in Appendix I.

Variables	(1) N	(2) Mean	(3) S.D.	(4) P25	(5) P50	(6) P75
North	31,647	0.36	0.48	0.00	0.00	1.00
AQI	31,647	88.77	27.80	71.77	84.06	99.26
Non-locally born executives	17,826	0.36	0.48	0.00	0.00	1.00
Non-locally educated executives	15,779	0.50	0.50	0.00	0.00	1.00
Executives with oversea experience	18,944	0.09	0.29	0.00	0.00	0.00
% of high education employees	14,835	0.26	0.21	0.11	0.19	0.36
% of low education employees	15,545	0.70	0.42	0.41	0.66	0.92
% of skilled employees	15,024	0.19	0.15	0.09	0.14	0.24
% of production and sales employees	14,455	0.14	0.16	0.03	0.07	0.17
% of financial and administrative employees	14,005	0.14	0.11	0.07	0.12	0.18
Inventions	31,647	0.34	0.83	0.00	0.00	0.00
Utility models	31,647	0.53	1.14	0.00	0.00	0.00
Inventions/employees	31,647	0.22	0.57	0.00	0.00	0.00
Utility models/employees	31,647	0.37	0.83	0.00	0.00	0.00
Inventions/R&D	13,879	0.07	0.18	0.00	0.00	0.02
Utility models/R&D	13,879	0.15	0.32	0.00	0.00	0.14
TFP	31,370	0.11	0.25	0.01	0.03	0.09
Q	31,647	2.76	2.39	1.41	2.04	3.17
Sales growth	31,647	0.25	0.85	-0.03	0.12	0.29
ROA	31,647	0.05	0.08	0.03	0.05	0.08
Firm size	31,647	21.68	1.35	20.77	21.50	22.36
Leverage	31,647	0.47	0.24	0.30	0.46	0.62
Cash flow	31,647	0.05	0.07	0.03	0.06	0.09
Capital expenditures	31,647	0.05	0.07	0.00	0.02	0.06
Firm age	31,647	1.91	0.89	1.39	2.08	2.64
Executive age	31,647	3.89	0.11	3.83	3.89	3.96
SOEs	31,647	0.40	0.49	0.00	0.00	1.00
Education expenditures	31,647	0.12	0.07	0.10	0.14	0.17
GDP growth	31,647	0.14	0.06	0.09	0.12	0.17
GDP per capita	31,647	9.98	10.48	3.14	6.78	13.33
Population density	31,647	6.49	0.71	6.10	6.55	6.87
Temperature	31,647	16.32	4.17	14.17	16.79	18.22

Table II

Differences of Characteristics between South and North Firms around the Heating Border

This table reports the differences of characteristics between south and north firms within a small margin around the heating boundary (2 degrees around the line of Qinling-Huai River). Panel A reports the mean and difference of firm and regional characteristics in the south and north sides of the boundary. Panel B reports the mean and difference of firm expected outcomes in the two sides of the boundary. The expected firm outcomes are the fitted values by regressing the outcome variables on the firm and regional characteristics as shown in Panel A. All variables are defined in Appendix I. The p-value of testing the difference is reported in column 4.

	South	North	Difference (North-South)	
	Mean	Mean	Estimate	p-value
	(1)	(2)	(3)	(4)
Panel A: Firm and regional characteristics				
Firm size	21.486	21.700	0.214	0.006
Leverage	0.437	0.448	0.011	0.506
Cash flow	0.057	0.059	0.002	0.670
Capital expenditures	0.051	0.047	-0.004	0.317
Firm age	1.725	1.662	-0.063	0.374
Executive age	3.908	3.911	0.003	0.696
SOEs	0.380	0.433	0.053	0.264
Education expenditures	0.158	0.189	0.031	0.000
GDP growth	0.139	0.132	-0.007	0.176
GDP per capita	7.082	2.705	-4.376	0.000
Population density	6.675	6.307	-0.367	0.000
Temperature	16.524	16.466	-0.058	0.133
Panel B: Expected firm outcomes:				
Non-locally born executives	-1.554	-1.510	0.044	0.184
Non-locally educated executives	-1.156	-1.195	-0.038	0.237
Executives with overseas experience	-2.993	-3.079	-0.086	0.119
% of high education employees	0.230	0.241	0.011	0.003
% of low education employees	0.676	0.658	-0.018	0.038
% of skilled employees	0.189	0.189	0.000	0.909
% of production and sales employees	0.127	0.126	-0.001	0.662
% of financial and administrative employees	0.114	0.111	-0.003	0.227
Inventions	0.343	0.349	0.006	0.737
Utility models	0.564	0.568	0.004	0.845
Inventions/employees	0.250	0.239	-0.011	0.373
Utility models/employees	0.427	0.410	-0.017	0.261
Inventions/R&D	0.098	0.091	-0.007	0.129
Utility models/R&D	0.183	0.171	-0.012	0.008
TFP	0.123	0.120	-0.003	0.620
Q	3.031	2.912	-0.119	0.190
Sales growth	0.261	0.248	-0.014	0.293
ROA	0.052	0.054	0.002	0.685

Table III
Air Pollution and Executive Talents

This table presents the results of RDD probit models estimating the effects of air pollution on executive talents. The dependent variables are *Non-locally born executives, Non-locally educated executives* and *Executives with overseas experience*. The key independent variable is *North*. Cubic polynomials are included. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. t-statistics based on a robust standard error estimate clustering at firm levels are reported in parentheses. At the bottom of the columns, the marginal effect of locating in the north (i.e., the difference of probability of having the respective executive talents in the south and north) is reported. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Dependent variables	(1) *Non-locally born executives*	(2) *Non-locally educated executives*	(3) *Executives with overseas experience*
North	**-0.615***** **(-3.23)**	**-0.371**** **(-2.20)**	**-0.448**** **(-2.57)**
Firm size	0.091*** (3.85)	0.061*** (2.76)	0.086*** (3.52)
Leverage	0.283** (2.16)	0.064 (0.58)	-0.380*** (-2.64)
Cash flow	-0.403 (-1.35)	0.264 (0.95)	-0.419 (-1.05)
Capital expenditures	-0.172 (-0.80)	-0.273 (-1.28)	0.389 (1.55)
Firm age	0.082** (2.51)	0.115*** (3.80)	-0.040 (-1.25)
Executive age	-0.420* (-1.88)	-0.761*** (-3.50)	-0.712*** (-2.62)
SOEs	0.033 (0.54)	-0.198*** (-3.26)	-0.319*** (-4.75)
Education expenditures	0.471 (1.13)	0.213 (0.53)	-0.208 (-0.42)
GDP per capita	-0.132 (-0.45)	-0.035 (-0.11)	0.363 (0.88)
GDP growth	0.009** (2.40)	0.011*** (3.12)	0.008** (2.01)
Population density	0.220*** (3.65)	-0.045 (-0.77)	0.091 (1.38)
Temperature	0.057** (2.50)	-0.019 (-0.86)	0.021 (0.80)
Polynomial	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Cluster	Firm	Firm	Firm
Observations	17,826	15,779	18,944
R-squared	0.0842	0.0714	0.0660
Pr(*North*=0|$\bar{X}$))-Pr(*North*=1|$\bar{X}$)	20.90%	13.70%	6.90%

Table IV
Air Pollution and Employee Structure

The results of RDD estimating the effects of air pollution on employee structure. Panel A presents the estimates of the effects on employee structure by education, which are measured by *% of high education employees* and *% of low education employees*. Panel B presents the estimates of the effects on employee structure by job functions, which are measured by *% of skilled employees*, *% of production and sales employees*, and *% of financial and administrative employees*. The key independent variable is *North*. Cubic polynomials are included. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. t-statistics based on a robust standard error estimate clustering at firm levels are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

	Panel A: Employee structure by education		**Panel B: Employee structure by job functions**		
	(1)	(2)	(3)	(4)	(5)
Dependent variables	*% of high education employees*	*% of low education employees*	*% of skilled employees*	*% of production and sales employees*	*% of financial and administrative employees*
North	**-0.044****	**0.048**	**-0.028****	**-0.002**	**-0.002**
	(-2.49)	**(1.33)**	**(-2.23)**	**(-0.16)**	**(-0.24)**
Firm size	0.012***	-0.028***	-0.000	0.006***	-0.017***
	(4.17)	(-5.20)	(-0.15)	(2.84)	(-9.59)
Leverage	-0.090***	0.080***	-0.074***	-0.032**	0.018*
	(-5.63)	(2.62)	(-6.63)	(-2.57)	(1.90)
Cash flow	-0.023	-0.308***	-0.018	0.122***	-0.032
	(-0.50)	(-3.46)	(-0.55)	(3.46)	(-1.30)
Capital expenditures	-0.289***	0.245***	-0.112***	-0.152***	-0.102***
	(-10.35)	(4.35)	(-5.53)	(-6.46)	(-6.40)
Firm age	-0.009***	0.051***	-0.009***	-0.007**	0.020***
	(-2.78)	(8.29)	(-3.84)	(-2.56)	(10.15)
Executive age	-0.065**	0.096*	0.028	0.029	-0.037***
	(-2.45)	(1.85)	(1.48)	(1.27)	(-2.58)
SOEs	0.018**	-0.027*	0.007	-0.022***	-0.009**
	(2.42)	(-1.91)	(1.25)	(-3.43)	(-2.24)
Education expenditures	0.241***	-0.413***	0.149***	0.095***	0.019
	(6.98)	(-5.18)	(5.42)	(3.09)	(1.00)
GDP per capita	0.217***	-0.460***	0.038	0.186***	-0.015
	(4.48)	(-4.67)	(1.08)	(4.41)	(-0.50)
GDP growth	0.001*	-0.001*	0.001***	0.000	-0.000
	(1.94)	(-1.68)	(2.81)	(0.63)	(-1.00)
Population density	0.024***	-0.030**	0.006	0.012**	0.006*
	(3.91)	(-2.54)	(1.25)	(2.40)	(1.96)
Temperature	0.010***	-0.017***	0.006***	0.006***	0.001
	(4.23)	(-3.62)	(3.52)	(2.82)	(0.96)
Polynomial	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm
Observations	14,835	15,545	15,024	14,455	14,005
R-squared	0.369	0.239	0.313	0.280	0.206

Table V
2SLS and Human Capital

This table presents the 2SLS results of estimating the effects of air quality on executive talents and employee structure. In the first stage, *AQI* is regressed on *North*. In the second stage, the fitted *AQI* from the first stage is regressed with the measures of executive talents (Panel A), which include *Non-locally born executives*, *Non-locally educated executives*, and *Executives with overseas experience*; the measures of employee structure by education (Panel B), which *include % of high education employees*，*% of low education employee*; and the measures of employee structure by job functions (Panel C), which includes *% of skilled employees*, *% of production and sales employees*，and *% of financial and administrative employees*. Cubic polynomials are included. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. t-statistics based on a robust standard error estimate clustering at firm levels are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Executive talents

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variables	*AQI*	*Non-locally born executives*	*AQI*	*Non-locally educated executives*	*AQI*	*Executives with overseas experience*
North	**3.402****		**5.876*****		**6.209*****	
	(2.50)		**(4.10)**		**(4.89)**	
Fitted *AQI*		**-0.059****		**-0.023***		**-0.009****
		(-2.04)		**(-1.93)**		**(-2.13)**
Polynomial	Yes	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Observations	17,826	17,826	15,779	15,779	18,944	18,944

Panel B: Employee structure by education

	(1)	(2)	(3)	(4)
Dependent variables	*AQI*	*% of high education employees*	*AQI*	*% of low education employees*
North	**9.946*****		**10.536*****	
	(6.71)		**(7.28)**	
Fitted *AQI*		**-0.004****		0.005
		(-2.30)		(1.30)
Polynomial	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	14,835	14,835	15,545	15,545

Panel C: Employee structure by job functions

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variables	*AQI*	*% of skilled employees*	*AQI*	*% of production and sales employees*	*AQI*	*% of financial and administrative employees*
North	**10.294*****		10.000***		9.941***	
	(7.09)		(6.57)		(6.63)	
Fitted *AQI*		**-0.003****		-0.000		-0.000
		(-2.09)		(-0.16)		(-0.24)
Polynomial	Yes	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Observations	15,024	15,024	14,455	14,455	14,005	14,005

Table VI
Local RDD and Human Capital

This table presents the local RDD results of estimating the effects of air quality on executive talents and employee structure. Only firms locating in regions with a distance smaller than 2 degrees in latitude from the Qinling-Huai River are included. Panel A reports the marginal effects of the local RDD probit model. The dependent variables are measures of executive talents, which include *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience.* Panels B and C report the results of the RDD OLS model. In Panel B, the dependent variables are the measures of employee structure by education, which include *% of high education employees* and *% of low education employees.* In Panel C, the dependent variables are the measures of employee structure by job functions which include *% of skilled employees*, *% of production and sales employees*, and *% of financial and administrative employees*. Firm characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Executive talents

	(1)	(2)	(3)
Dependent variables	*Non-locally born executives*	*Non-locally educated executives*	*Executives with overseas experience*
North	**-0.607***** **(-7.18)**	**-0.310***** **(-4.15)**	**-0.604***** **(-4.88)**
Firm characteristics controls	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Observations	4,346	3,788	4,631
R-squared	0.073	0.075	0.100

Panel B: Employee structure by education

	(1)	(2)
Dependent variables	*% of high education employees*	*% of low education employees*
North	**-0.021**** **(-1.99)**	0.015 (0.71)
Firm characteristics controls	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes
Observations	4,045	4,201
R-squared	0.342	0.185

Panel C: Employee structure by job functions

	(1)	(2)	(3)
Dependent variables	*% of skilled employees*	*% of production and sales employees*	*% of financial and administrative employees*
North	**-0.017**** **(-2.23)**	0.012 (1.40)	0.008 (1.52)
Firm characteristics controls	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Observations	4,074	3,968	3,813
R-squared	0.280	0.315	0.264

Table VII
Concerns for Amenity in Response to Air Pollution

This table reports the estimates of regressions examining the regional concerns for health amenity and willingness to flee in response to air pollution. Panel A reports the estimates of the following model:

$$\%Change\ of\ Search\_Health_{c,t+1} = beta_1 * \%Change\ of\ AQI_{c,t} + Control + e_{c,t+1}$$

where $\%Change\ of\ Search\_Health_{c,t+1}$ is the percentage change of daily Baidu search volume index by the word of "health (健康)" in city *c* on day *t+1*; $\%Change\ of\ AQI_{c,t}$ is the percentage change of AQI in region *c* on day *t*. Panel B reports the estimates of the following model:

$$\%Change\ of\ Search\_JobQuit_{c,t+1} = beta_2 * \%Change\ of\ AQI_{c,t} + Control + e_{c,t+1}$$

where $\%Change\ of\ Search\_JobQuit_{c,t+1}$ is the percentage change of daily Baidu search volume index by the word of "quit job (辞职)" in city *c* on day *t+1*. In both models, We include year fixed effects. Standard errors are estimated by clustering at two ways of city and date levels. The t statistics are reported in parentheses. Significance at the 10%, 5%, and 1% level is indicated by *, **, and ***, respectively.

	Panel A: Concern for health in response to air pollution		**Panel B: Willingness to flee in response to air pollution**	
	(1)	(2)	(3)	(4)
Dependent variable	*%Change of Search_Health $_{c,t+1}$*		*%Change of Search_QuitJob $_{c,t+1}$*	
%Change of AQI $_t$	**0.014***** **(3.45)**	**0.011***** **(2.90)**	**0.022***** **(3.38)**	**0.014**** **(2.41)**
Education expenditures		0.261** (2.36)		-1.139** (-2.10)
GDP growth		-0.018 (-0.50)		0.336 (1.20)
GDP per capita		0.000 (0.61)		0.014** (2.43)
Temperature		-0.003** (-2.26)		-0.004 (-0.58)
Population density		0.052*** (6.61)		0.173*** (5.81)
Observations	124,128	124,128	124,128	124,128
Year FEs	Yes	Yes	Yes	Yes
Cluster	City, date	City, date	City, date	City, date
R-squared	0.004	0.011	0.011	0.102

Table VIII

The Impact of Air Pollution and Heterogeneity in Concerns for Amenity

This table reports the estimates of regressions examining how the effects of air pollution on human capital vary with heterogeneity in concerns for Amenity. *Health-Pollution sensitivity* is the estimated beta of the following time-series model: *%Change of Search_Health* $_{t+1}$=beta**%Change of AQI* $_t$ + FEs + *e* $_t$ where *%Change of Search_Health* $_{t+1}$ is the percentage change of daily Baidu search volume index by the keyword of "health (健康)" in a region on day t+1; *%Change of AQI* $_t$ is the percentage change of AQI in a region on day t. The health-related career concern is measured by *Job quit-pollution sensitivity*, which is the estimated beta of the following time-series model: *%Change of Search_JobQuit* $_{t+1}$=beta**%Change of AQI* $_t$ + FEs + *e* $_t$ where *%Change of Search_JobQuit* $_{t+1}$ is the percentage change of daily Baidu search volume index by the keyword of "quit job (辞职)" in a region on day t+1. In both models, FEs are the month, weekday, and Chinese New Year fixed effects. The model is estimated for each region in each year. We re-estimate the global RDD regressions of human capital by including the interaction term between the estimated betas and *North*. Human capital measures include executive talent variables (i.e., *Non-locally born executives*, *Non-locally educated executives*, and *Executives with overseas experience*), employee structure by education (i.e., *% of high education employees* and *% of low education employees*), and employee structure by job functions (i.e., *% of skilled employees*，*% of production and sales employees*，and *% of financial and administrative employees*). Panel A reports the results where the estimated beta is *Health-pollution sensitivity*. Panel B reports the results where the estimated beta is *Job quit-pollution sensitivity*. In all regressions, cubic polynomials are included. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. t-statistics based on a robust standard error estimate clustering at firm levels are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Health concern to air pollution sensitivity								
	A1: Executive talents			**A2: Employee structure by education**		**A3: Employee structure by job functions**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variables	*Non-locally born executives*	*Non-locally educated executives*	*Executives with overseas experience*	*% of high education employees*	*% of low education employees*	*% of skilled employees*	*% of production and sales employees*	*% of financial and administrative employees*
North	-0.867***	-0.335*	-0.456**	-0.041**	0.045	-0.026**	-0.001	-0.002
	(-4.26)	(-1.93)	(-2.51)	(-2.37)	(1.27)	(-2.10)	(-0.09)	(-0.28)
North * Health-pollution sensitivity	**-1.361*** **	**-0.906** **	**-0.125**	**-0.102*** **	0.117	**-0.071** **	-0.047	0.017
	(-3.03)	**(-2.05)**	**(-0.19)**	**(-2.61)**	(1.09)	**(-2.33)**	(-1.41)	(0.72)
Health-pollution sensitivity	0.442**	-0.153	-0.452*	0.045**	-0.083*	0.014	0.022	-0.009
	(2.04)	(-0.70)	(-1.68)	(2.14)	(-1.69)	(0.91)	(1.28)	(-0.84)
Polynomial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Observations	9,122	9,788	12,432	14,835	15,545	15,024	14,455	14,005
R-squared	0.084	0.066	0.062	0.369	0.239	0.314	0.280	0.206

Panel B: Job quit to air pollution sensitivity

	B1: Executive talents			**B2: Employee structure by education**		**B3: Employee structure by job functions**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variables	*Non-locally born executives*	*Non-locally educated executives*	*Executives with overseas experience*	*% of high education employees*	*% of low education employees*	*% of skilled employees*	*% of production and sales employees*	*% of financial and administrative employees*
North	-0.856***	-0.338*	-0.477***	-0.042**	0.049	-0.027**	-0.003	-0.002
	(-4.21)	(-1.96)	(-2.62)	(-2.37)	(1.36)	(-2.16)	(-0.22)	(-0.21)
North * Job quit-pollution sensitivity	**-0.694****	**-0.738****	**-0.075**	**-0.058****	-0.006	**-0.018**	0.008	0.006
	(-2.17)	**(-2.56)**	**(-0.21)**	**(-2.09)**	(-0.09)	**(-0.84)**	(0.35)	(0.35)
Job quit-pollution sensitivity	-0.167	0.050	0.276	0.011	-0.017	0.000	0.011	-0.011
	(-0.92)	(0.27)	(1.30)	(0.72)	(-0.41)	(0.04)	(0.80)	(-1.17)
Polynomial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Observations	9,122	9,788	12,432	14,835	15,545	15,024	14,455	14,005
R-squared	0.085	0.066	0.062	0.369	0.239	0.313	0.280	0.206

Table IX
Regional Evidence: Air Pollution and Human Capital

This table presents the RDD results of estimating the effects of air quality on regional levels of human capital. Human capital measures include *Skilled migrants*, *Non-skilled migrants*, *High education migrants*, *Low education migrants* and *Tourists*. Migrant information comes from the 2010 and 2000 population census of PRC. *Tourists* is the number of foreign tourists scaled by the total population in a region in a year (with data available from 2000 to 2015). In all regressions, cubic polynomials are included. Regional characteristics, year, and longitude fixed effects are included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

	(1)	(2)	(3)	(4)	(5)
Dependent variables	*Skilled migrants*	*Non-skilled migrants*	*High education migrants*	*Low education migrants*	*Tourists*
North	**-0.009***	-0.122	**-0.019*****	-0.155	**-0.011*****
	(-1.70)	(-1.33)	**(-2.65)**	(-1.54)	**(-5.65)**
Education expenditures	0.064**	2.042***	0.075*	2.425***	0.042***
	(1.97)	(3.78)	(1.82)	(4.07)	(4.29)
GDP growth	-0.000	0.019	0.000	0.012	-0.002
	(-0.03)	(0.20)	(0.02)	(0.11)	(-0.58)
GDP per capita	0.003***	0.057***	0.003***	0.064***	0.002***
	(6.87)	(7.39)	(4.70)	(7.54)	(14.83)
Population density	0.002**	0.022*	0.001	0.021	0.000
	(2.14)	(1.72)	(1.21)	(1.47)	(0.65)
Temperature	0.002	-0.036	0.005*	-0.039	0.004***
	(1.14)	(-1.14)	(1.89)	(-1.13)	(6.36)
Polynomial	Yes	Yes	Yes	Yes	Yes
Year and longitude FEs	Yes	Yes	Yes	Yes	Yes
Observations	387	387	387	387	3,522
R-squared	0.342	0.496	0.167	0.489	0.375

Table X
Corporate Innovation and Productivity

This table presents the RDD results of estimating the effects of air pollution on corporate innovation and productivity. Corporate innovation is measured by *Inventions/employees* and *Utility models/employees*. Corporate productivity measure is *TFP*. The key independent variable is *North*. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Panel A reports the estimates of global RDD where cubic polynomials are included. Panel B reports the estimates of 2SLS where the IV is *North* and the fitted *AQI* is regressed with corporate innovation and productivity (cubic polynomials are included). Panel C reports the estimates of local RDD where only firms locating in regions with a distance smaller than 2 degrees in latitude from the Qinling-Huai River are included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Global RDD

	(1)	(2)	(3)
Dependent variables	*Inventions/employees*	*Utility models/employees*	*TFP*
North	**-0.331***** **(-9.96)**	**-0.395***** **(-7.23)**	**-0.030**** **(-2.28)**
Firm size	0.019*** (3.18)	0.009 (1.19)	-0.027*** (-9.75)
Leverage	-0.181*** (-7.02)	-0.185*** (-5.02)	0.021 (1.27)
Cash flow	-0.050 (-0.79)	-0.102 (-1.13)	0.982*** (22.68)
Capital expenditures	0.076 (1.50)	0.194*** (2.61)	-0.516*** (-23.45)
Firm age	-0.016** (-2.46)	-0.020** (-1.96)	-0.018*** (-5.50)
Executive age	-0.068 (-1.36)	-0.171** (-2.37)	-0.072*** (-3.48)
SOEs	-0.014 (-0.93)	-0.046** (-2.32)	-0.019*** (-3.04)
Education expenditures	-0.904*** (-9.44)	-2.260*** (-14.92)	0.128*** (4.90)
GDP per capita	-0.276*** (-3.96)	-0.379*** (-3.72)	-0.039 (-1.30)
GDP growth	0.006*** (5.68)	0.008*** (4.87)	0.001** (2.36)
Population density	0.011 (0.88)	-0.017 (-0.89)	0.021*** (4.14)
Temperature	-0.007* (-1.79)	-0.021*** (-3.32)	0.003* (1.75)
Polynomial	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Cluster	Firm	Firm	Firm
Observations	31,647	31,647	31,370
R-squared	0.167	0.223	0.252

Panel B: 2SLS

	(1)	(2)	(3)
Dependent variables	*Inventions/employees*	*Utility models/employees*	*TFP*
Fitted AQI	**-0.071***** **(-3.89)**	**-0.085***** **(-3.70)**	**-0.006**** **(-2.01)**
Polynomial	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Cluster	Firm	Firm	Firm
Observations	31,647	31,647	31,370
F-value of IV strength test	16.43	16.43	16.24

Panel C: Local RDD

	(1)	(2)	(3)
Dependent variables	*Inventions/employees*	*Utility models/employees*	*TFP*
North	**-0.234***** **(-9.45)**	**-0.222***** **(-6.33)**	**-0.022**** **(-2.22)**
Firm controls	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes
Observations	8,514	8,514	8,514
R-squared	0.168	0.206	0.244

Table XI
Firm Value and Sales Growth

This table presents the RDD results of estimating the effects of air pollution on firm value (*Q*) and sales growth (*Sales growth*). The key independent variable is *North*. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Panel A reports the estimates of global RDD where cubic polynomials are included. Panel B reports the estimates of 2SLS where the IV is *North* and the fitted *AQI* is regressed with corporate innovation and productivity (cubic polynomials are included). Panel C reports the estimates of local RDD where only firms locating in regions with a distance smaller than 2 degrees in latitude from the Qinling-Huai River are included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Global RDD

	(1)	(2)
Dependent variables	*Q*	*Sales growth*
North	**-0.682*****	**-0.128*****
	(-3.76)	**(-4.49)**
Firm size	-0.935***	-0.003
	(-19.78)	(-0.46)
Leverage	1.230***	0.286***
	(4.20)	(8.86)
Cash flow	3.211***	1.842***
	(5.37)	(17.65)
Capital expenditures	-0.845***	1.305***
	(-3.97)	(12.66)
Firm age	-0.017	-0.038***
	(-0.46)	(-4.02)
Executive age	0.082	-0.323***
	(0.38)	(-7.04)
SOEs	-0.173***	-0.072***
	(-3.05)	(-5.78)
Education expenditures	0.878***	0.389***
	(2.89)	(5.65)
GDP per capita	0.430	0.039
	(1.40)	(0.40)
GDP growth	0.002	0.001
	(0.54)	(1.42)
Population density	0.185***	-0.006
	(3.65)	(-0.63)
Temperature	0.040*	0.004
	(1.92)	(0.88)
Polynomial	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes
Cluster	Firm	Firm
Observations	31,647	31,647
R-squared	0.265	0.052

Panel B: 2SLS

Dependent variables	(1) *Q*	(2) *Sales growth*
Fitted AQI	**-0.147***** **(-2.82)**	**-0.028***** **(-3.00)**
Polynomial	Yes	Yes
Firm and regional controls	Yes	Yes
Year, Industry, and Longitude FEs	Yes	Yes
Cluster	Firm	Firm
Observations	31,647	31,647
F statistic for weak identification	16.43	16.43

Panel C: Local RDD

Dependent variables	(1) *Q*	(2) *Sales growth*
North	**-0.154*** **(-1.80)**	**-0.068*** **(-1.77)**
Firm controls	Yes	Yes
Year, Industry, and Longitude FEs	Yes	Yes
Observations	8,514	8,514
R-squared	0.316	0.068

Table XII
Firm Performance and Human Capital Dependence

This table reports the estimates of regressions examining how the effects of air pollution on corporate performance vary with firms' human capital dependence. The dependence of corporate performance on executive talent human capital is the estimated coefficient of model that regresses firm performance measure on the executive talent index (i.e. the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls. The dependence of corporate performance on high-quality employee human capital is the estimated coefficient of model that regresses firm performance measure on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls. The human capital dependence measures are estimated for corporate outcome variables, including *Inventions/employees*, *Utility models/employees*, *TFP*, *Q*, and *Sales growth, on the human capital*, respectively. The estimated human capital dependence measure for a variable of corporate performance is interacted with *North* and added to the model that explains that measure of performance. In all regressions, cubic polynomials are included. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Appendix I presents detailed definitions of all variables. Panel A reports the results for the dependence of corporate performance on executive talent human capital. Panel B reports the results for the dependence of corporate performance on high-quality employee human capital. t-statistics based on a robust standard error estimate clustering at firm levels are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Executive talent human capital dependence

	(1)	(2)	(3)	(4)	(5)
Dependent variables	*Inventions/employees*	*Utility models/employees*	*TFP*	*Q*	*Sales growth*
North	-0.319***	-0.368***	-0.030**	-0.490***	-0.128***
	(-9.43)	(-6.81)	(-2.27)	(-3.12)	(-4.49)
North * I/E-talents dependence	**-0.165****				
	(-1.98)				
North * UM/E-talents dependence		**-0.349*****			
		(-5.61)			
North * TFP-talents dependence			**-0.005****		
			(-2.01)		
North * Q-talents dependence				**-0.027*****	
				(-4.48)	
North * SG-talents dependence					**-0.002***
					(-1.94)
Polynomial	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm
Observations	31,647	31,647	31,370	31,647	31,647
R-squared	0.167	0.224	0.252	0.336	0.052

Panel B: High-quality employee human capital dependence

Dependent variables	(1) *Inventions/employees*	(2) *Utility models/employees*	(3) *TFP*	(4) *Q*	(5) *Sales growth*
North	-0.351***	-0.467***	-0.024	-0.549***	-0.193***
	(-7.73)	(-5.70)	(-0.92)	(-2.59)	(-5.02)
North * I/E-employees dependence	**-0.061***** **(-2.65)**				
North * UM/E-employees dependence		**-0.154***** **(-4.81)**			
North * TFP-employees dependence			**-0.038** **(-0.68)**		
North * Q-employees dependence				**-0.108***** **(-3.64)**	
North * SG-employees dependence					**-0.060**** **(-2.44)**
Polynomial	Yes	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm
Observations	15,904	15,904	14,736	15,904	15,904
R-squared	0.193	0.264	0.303	0.343	0.066

Table XIII
Air Pollution and Regional Innovation and New Product Development

This table presents the RDD results of estimating the effects of air quality on regional innovation and new product development. The development of innovation and new products of enterprises in a region include *Patents/R&D*, *Patents/R&D researchers*, *New products/R&D*, *New products/R&D researchers* (with data available from 2008 to 2016). In all regressions, cubic polynomials are included. Regional characteristics, year, and longitude fixed effects are included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel B: Innovation and new product development				
	(1)	(2)	(3)	(4)
Dependent variables	*Patents/R&D*	*Patents/R&D researchers*	*New products/R&D*	*New products/R&D researchers*
North	**-0.001***** **(-4.31)**	**-0.035***** **(-4.97)**	**-0.001***** **(-6.19)**	**-0.033***** **(-7.81)**
Education expenditures	0.005*** (3.86)	0.045 (1.25)	0.004*** (3.95)	0.004 (0.18)
GDP growth	-0.000 (-0.06)	-0.001 (-1.16)	0.000 (1.44)	0.000 (0.95)
GDP per capita	0.000 (1.36)	0.000 (1.42)	-0.000* (-1.68)	-0.001*** (-3.45)
Population density	0.000* (1.90)	0.002** (2.14)	0.000*** (4.55)	0.003*** (5.53)
Temperature	0.000*** (3.33)	0.007*** (3.13)	0.000*** (2.77)	0.004*** (3.09)
Polynomial	Yes	Yes	Yes	Yes
Year and longitude FEs	Yes	Yes	Yes	Yes
Observations	2,103	2,103	2,103	2,103
R-squared	0.355	0.557	0.569	0.382

Appendix I
Variable Definitions and Data Sources

Variables	Definitions	Sources	Period
Firm outcomes variables			
Non-locally born executives	1 if the CEO or chairman was born in a region that is outside the province in which the firm is domiciled and 0 otherwise. It is filled with a missing value if the CEO and chairman's birthplace information cannot be identified.	GTA_TMT/CSMAR, CCXE, and Manually collected	2000-2016
Non-locally educated executives	1 if the CEO or chairman got a degree from a university or college in a region that is outside the province in which the firm is domiciled and 0 otherwise. It is filled with a missing value if the CEO and chairman's education information cannot be identified.	GTA_TMT/CSMAR, CCXE, and Manually collected	2000-2016
Executives with overseas experience	1 if the CEO or chairman has study or working experience abroad and 0 otherwise. It is filled with a missing value if the CEO and chairman's education and working information cannot be identified.	GTA_TMT/CSMAR, CCXE, and Manually collected	2000-2016
% of high education employees	The number of employees with a bachelor degree or above, scaled by the total number of employees. It is filled with a missing value if the information is not available.	Employee structure/Wind	2011-2016
% of low education employees	The number of employees whose highest education level is high school or below, scaled by the total number of employees. It is filled with a missing value if the information is not available.	Employee structure/Wind	2011-2016
% of skilled employees	The number of technical employees, scaled by the total number of employees. It is filled with a missing value if the information is not available.	Employee structure/Wind	2011-2016
% of production and sales employees	The number of production and sales employees, scaled by the total number of employees. It is filled with a missing value if the information is not available.	Employee structure/Wind	2011-2016
% of financial and administrative employees	The number of financial, HR, administrative employees, scaled by the total number of employees. It is filled with a missing value if the information is not available.	Employee structure/Wind	2011-2016
Inventions	Log(the number of invention patent applications in the region where the firm headquarters + 1).	GTA_LCPT/CSMAR	2000-2016
Utility models	Log(the number of utility model patent applications in the region where the firm headquarters+ 1).	GTA_LCPT/CSMAR	2000-2016
Inventions/employees	Log (1+ the number of invention patent applications in the region where the firm headquarters, scaled by employees (in thousand))	GTA_LCPT/CSMAR, Employee structure/Wind	2000-2016
Utility models/employees	Log (1+ the number of utility model patent applications in the region where the firm headquarters, scaled by employees (in thousand))	GTA_LCPT/CSMAR, Employee structure/Wind	2000-2016
Inventions/R&D	Log(the number of invention patent applications in the region where the firm headquarters, scaled by million R&D expenditures + 1).	GTA_LCPT/CSMAR; Wind	2007-2016

Utility models/R&D	Log(the number of utility model patent applications in the region where the firm headquarters, scaled by million R&D expenditures + 1).	GTA_LCPT/CSMAR; Wind	2007-2016
TFP	Total factor productivity, estimated for each firm using the methodology developed by Levinsohn-Petrin (2003) where the output (y) is the firm's net profits (net value added); firm labor (L) is the number of employees; and firm capital is property, plant, and equipment (PPE).	GTA_FS/CSMAR	2000-2016
Q	The market value of total equity over book value of total equity.	GTA_FS/CSMAR; GTA_TRD/CSMAR	2000-2016
Sales growth	The annual growth rate of total sales.	GTA_FS/CSMAR	2000-2016
Firm explanatory variables:			
North	1 if a region's latitude distance from the line of Qinling-Huai River (the former - the latter) is positive and 0 otherwise.	SAS Maps, and Manually collected	2000-2016
Firm size	Log(total assets).	GTA_FS/CSMAR	2000-2016
Leverage	Total liability/total assets.	GTA_FS/CSMAR	2000-2016
Cash flow	Operating income before depreciation and amortization/total assets.	GTA_FS/CSMAR	2000-2016
Capital expenditures	Capital expenditures over total assets.	GTA_FS/CSMAR	2000-2016
Firm age	The number of years since the establishment of the firm.	GTA_TRD/CSMAR	2000-2016
Executive age	The average age of a firm CEO and chairman of the board of directors.	GTA_TMT/CSMAR	2000-2016
SOEs	1 if the firm is ultimately controlled by the state government and 0 otherwise.	GTA_HLD/CSMAR	2000-2016
I/E-talents dependence	The estimated coefficient of model that regresses *Inventions/employees* on the executive talent index (i.e. the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_LCPT/CSMAR, Employee structure/Wind, GTA_TMT/CSMAR, GTA_FS/CSMAR	2000-2016
UM/E-talents dependence	The estimated coefficient of model that regresses *Utility models/employees* on the executive talent index (i.e. the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_LCPT/CSMAR, Employee structure/Wind, GTA_TMT/CSMAR, GTA_FS/CSMAR	2000-2016
TFP-talents dependence	The estimated coefficient of model that regresses *TFP* on the executive talent index (i.e. the average of *Non-locally*	GTA_TMT/CSMAR,	2000-2016

	born executives, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_FS/CSMAR	
Q-talents dependence	The estimated coefficient of model that regresses *Q* on the executive talent index (i.e. the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_TMT/CSMAR, GTA_FS/CSMAR	2000-2016
SG-talents dependence	The estimated coefficient of model that regresses *Sales growth* on the executive talent index (i.e. the average of *Non-locally born executives*, *Non-locally educated executives* and *Executives with overseas experience*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_TMT/CSMAR, GTA_FS/CSMAR	2000-2016
I/E-employees dependence	The estimated coefficient of model that regresses *Inventions/employees* on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_LCPT/CSMAR, Employee structure/Wind, GTA_FS/CSMAR	2011-2016
UM/E-employees dependence	The estimated coefficient of model that regresses *Utility models/employees* on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	GTA_LCPT/CSMAR, Employee structure/Wind, GTA_FS/CSMAR	2011-2016
TFP-employees dependence	The estimated coefficient of model that regresses *TFP* on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	Employee structure/Wind, GTA_FS/CSMAR	2011-2016
Q-employees dependence	The estimated coefficient of model that regresses *Q* on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	Employee structure/Wind, GTA_FS/CSMAR	2011-2016

SG-employees dependence	The estimated coefficient of model that regresses *Sales growth* on the high-quality employee index (i.e. the average of *% of high education employees* and *% of skilled employees*) within an industry over the past five years, with firm characteristics (i.e. *Firm size*, *Leverage*, *Cash flow*, *Capital expenditures*, *Firm age*, *Executive age*, and *SOEs*) included as controls.	Employee structure/Wind, GTA_FS/CSMAR	2011-2016
Regional outcome variables:			
Skilled migrants	The skilled and technical migrants/total population in a region; Migrants are those who are living in a province but their household registration place is in other provinces.	The 5th and 6th population census of PRC/NBS	2000, 2010
Non-skilled migrants	(Total migrants - skilled and technical migrants)/total population in a region; Migrants are those who are living in a province but their household registration place is in other provinces.	The 5th and 7th population census of PRC/NBS	2000, 2010
High education migrants	Migrants with a bachelor degree or above/total population in a region; Migrants are those who are living in a province but their household registration place is in other provinces.	The 5th and 8th population census of PRC/NBS	2000, 2010
Low education migrants	(Migrants whose highest education level is high school or below)/total population in a region; Migrants are those who are living in a province but their household registration place is in other provinces.	The 5th and 9th population census of PRC/NBS	2000, 2010
Tourists	The number of foreign tourists/total population in a region in a year.	GTA_CRE/CSMAR	2000-2015
Patents/R&D	The number of total patent applications/the total R&D expenditures (10k) of all enterprises in a region in a year.	GTA_CRE/CSMAR	2008-2016
Patents/R&D researchers	The number of patent applications/the total R&D researchers of all enterprises in a region in a year.	GTA_CRE/CSMAR	2008-2016
New products/R&D	The number of new products issued/the total R&D expenditures (10k) of all enterprise in a region in a year.	GTA_CRE/CSMAR	2008-2016
New products/R&D researchers	The number of new products/the total R&D researchers of all enterprises in a region in a year.	GTA_CRE/CSMAR	2008-2016
Regional explanatory variables:			
Education expenditures	Government expenditures in education over the total government expenditures for a region in a year.	GTA_CRE/CSMAR	2000-2016
Population density	Log(number of population per square kilometer) for a region in a year.	GTA_CRE/CSMAR	2000-2016
GDP growth	GDP growth rate for a region in a year.	GTA_CRE/CSMAR	2000-2016
GDP per capita	Log(GDP per capita) for a region in a year.	GTA_CRE/CSMAR	2000-2016
Temperature	The monthly average temperature in a region in a year.	GTA_CRE/CSMAR	2000-2016
AQI	The monthly average of air quality index for a region in the winter (Oct, Nov, Dec, Jan, Feb, and Mar). China's	GTA_CRE/CSMAR	2000-2016

	Ministry of Environmental Protection (MEP) is responsible for measuring the level of air pollution in China and publishing the air quality index.		
%Change of AQI $_{c,\ t}$	The percentage change of AQI in city *c* on day t.	GTA_CRE/CSMAR	2000-2016
%Change of Search_Health $_{c,\ t+1}$	The percentage change of daily Baidu search volume index by the keyword of "health (健康)" in city *c* on day t+1.	Baidu.com	2011-2016
%Change of Search_Quit Job $_{c,\ t+1}$	The percentage change of daily Baidu search volume index by the keyword of "quit job (辞职)" in city *c* on day t+1.	Baidu.com	2011-2016
Health-pollution sensitivity	The estimated beta of the following time-series model: *%Change of Search_Health* $_{t+1}$=beta**%Change of AQI* $_t$ + FEs + e_t where *%Change of Search_Health* $_{t+1}$ is the percentage change of daily Baidu search volume index by the keyword of "health (健康) " in a city on day t+1; *%Change of AQI* $_t$ is the percentage change of AQI in a region on day t. FEs are the month, weekday, and Chinese New Year fixed effects. The model is estimated for each region in each year.	Baidu.com, GTA_CRE/CSMAR	2011-2016
Job quit-pollution sensitivity	The estimated beta of the following time-series model: *%Change of Search_JobQuit* $_{t+1}$=beta**%Change of AQI* $_t$ + FEs + e_t where *%Change of Search_JobQuit* $_{t+1}$ is the percentage change of daily Baidu search volume index by the keyword of "quit job (辞职) " in a city on day t+1; *% Change of AQI* $_t$ is the percentage change of AQI in a region on day t. FEs are the month, weekday, and Chinese New Year fixed effects. The model is estimated for each region in each year.	Baidu.com, GTA_CRE/CSMAR	2011-2016

Appendix II
Corporate Innovation and Productivity

This table presents the RDD results of estimating the effects of air pollution on corporate innovation. Corporate innovation measures include *Inventions*, *Utility models*, *Inventions/R&D*, and *Utility models/R&D*. The key independent variable is *North*. Firm and regional characteristics are controlled. Year, industry, and longitude fixed effects are also included. Panel A reports the estimates of global RDD where cubic polynomials are included. Panel B reports the estimates of 2SLS where the IV is *North* and the fitted *AQI* is regressed with corporate innovation and productivity (cubic polynomials are included). Panel C reports the estimates of local RDD where only firms locating in regions with a distance smaller than 2 degrees in latitude from the Qinling-Huai River are included. Appendix I presents detailed definitions of all variables. t-statistics are reported in parentheses. Significance at 10%, 5% and 1% levels indicated by *, **, and ***, respectively.

Panel A: Global RDD

	(1)	(2)	(3)	(4)
Dependent variables	*Inventions*	*Utility models*	*Inventions/R&D*	*Utility models/R&D*
North	**-0.418*** **	**-0.461*** **	**-0.107*** **	**-0.171*** **
	(-7.95)	**(-5.77)**	**(-8.02)**	**(-5.42)**
Polynomial	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	31,647	31,647	13,879	13,879
R-squared	0.205	0.248	0.122	0.134

Panel B: 2SLS

	(1)	(2)	(3)	(4)
Dependent variables	*Inventions*	*Utility models*	*Inventions/R&D*	*Utility models/R&D*
Fitted AQI	**-0.090*** **	**-0.099*** **	**-0.014*** **	**-0.023*** **
	(-3.72)	**(-3.46)**	**(-4.33)**	**(-3.67)**
Polynomial	Yes	Yes	Yes	Yes
Firm and regional controls	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	31,647	31,647	13,879	13,879
F-value of IV strength test	16.43	16.43	23.72	23.72

Panel C: Local RDD

	(1)	(2)	(3)	(4)
Dependent variables	*Inventions*	*Utility models*	*Inventions/R&D*	*Utility models/R&D*
North	**-0.342*****	**-0.326*****	**-0.061*****	**-0.066*****
	(-10.81)	**(-7.35)**	**(-5.77)**	**(-3.40)**
Firm controls	Yes	Yes	Yes	Yes
Year, industry, and longitude FEs	Yes	Yes	Yes	Yes
Observations	8,514	8,514	3,814	3,814
R-squared	0.218	0.240	0.118	0.129