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# Air Pollution and Corporate Innovation: Does Top Management Quality Mediate and Government Talent Policy Moderate?

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**Abstract:** Air pollution not only poses significant threats to the physical and mental well-being of individuals, but it also has the potential to trigger a regional brain drain, thus inhibiting corporate innovation performance. This study explores the impact of air pollution on corporate innovation from the perspective of top management quality. We find that lower air quality significantly reduces the quality of corporate top management, thereby reducing their innovation output. However, local government talent attention alleviates the negative impact of air pollution on corporate innovation. Further analysis reveals that the local government's environmental attention aggravates the negative effects of air pollution on corporate innovation. Finally, executive compensation alleviates the negative impact of air pollution on corporate innovation.

**Keywords:** air pollution; corporate innovation; top management quality; talent policy

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## 1. Introduction

Severe air pollution problems accompany the rapid development of emerging economies. China, for example, ranked 168th out of 180 participating countries and regions in the Air Quality Index [1]. Air pollution adversely affects physiological function, cognitive abilities, and mental wellness, which brings significant negative externalities to human production and life. It significantly increases residents' risk of cardiovascular and respiratory diseases [2], shortens life expectancy, increases hospitalization and mortality rates [3,4], and predisposes them to anxiety and depression [5,6], as well as reducing subjective well-being [7,8]. Globally, governments and international organizations have implemented a number of green policies to address the issue of air pollution. One such initiative is the Paris Agreement, which was signed in 2016 and aims to limit the increase in the average global temperature while directly addressing the issue of greenhouse gas emissions [9]. The BreathLife campaign was initiated by the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the Climate and Clean Air Coalition (CCAC) in the same year in order to mitigate the effects of air pollution on public health [10]. The 50th anniversary of the Clean Air Act was commemorated in the United States in 2020. This legislation was initially implemented in 1970 with the aim of regulating air pollution and enhancing air quality in the United States [11]. Continued efforts and policy support are needed to further improve air quality. Air pollution has a direct negative impact on the standard of human capital inputs used by businesses, which is manifested in the generation of slacking behavior, reducing the productivity of individuals [12] and further inhibiting their innovative vitality [13,14].

Innovation is considered to be significantly influenced by human capital [15]. Air pollution not only directly undermines the innovative vitality of the individual labor force but also leads to the loss of the regional and corporate stock of talent. Based on the theory of "voting with their feet" [16,17], residents' health costs rise [18], and the propensity of residents to migrate increases [19,20], as a result of health issues linked to air pollution. A highly qualified workforce, in particular, would be more aware of the quality of the air [21]. This highly skilled workforce is more likely to pay to improve air quality and reduce air pollution as they can afford the fees associated with changing jobs [22,23]. As a result, air pollution causes a decrease in the human capital reserves of businesses and consequently discourages firms from innovating, leading to a "brain drain effect" [12,13,24,25]. Nonetheless, existing research has studied the brain drain effect associated with air pollution with more consideration of the loss of labor in general or highly qualified labor in particular, ignoring the unique role of corporate top management. We aim to make progress in closing this research gap in the current body of literature.

China faces the dual challenge of advancing environmental governance while sustaining robust economic development. In 2023, China's 339 prefectural and larger cities did not comply with the air quality criteria, which provides a suitable research scenario for our study [26]. We used a sample of public companies in the Chinese Shanghai and Shenzhen markets from 2004 to 2019 to empirically study the effects of air pollution (PM 2.5 concentration) on corporate innovation with respect to the locations of the companies. We focused on testing the mediating role played by the quality of top management, as well as the role of government talent policies as a moderator. In addition, this study analyzes the moderating role of government environmental attention and executive compensation. Finally, the robustness of the results is verified through rigorous endogeneity and robustness tests. We obtained four main findings. First, air pollution significantly inhibits firms' innovation output. Second, air pollution significantly reduces the quality of corporate top management. Third, the top management quality mediates the effect of air pollution on firms' innovation. Fourth, local government talent policies have been shown to alleviate the detrimental influences of air pollution on firms' innovative capabilities to a significant degree. Moreover, this study reveals that executive compensation mitigates the adverse effect of air pollution on firm innovation to some extent. Meanwhile, government environmental attention exacerbates the adverse effect of air pollution on firm innovation. These results offer governments and businesses a theoretical foundation and empirical support for preventing and controlling air pollution, optimizing talent conservation, and maximizing talent benefits. Furthermore, they hold great theoretical and practical importance in advancing the superior growth of transition economies.

This study makes contributions in the following three areas: First, it improves upon studies on air pollution and business economic behavior. Air pollution-induced human capital flows and their microeconomic consequences have received increasing attention, with existing studies focusing more on the general labor force or generalized highly qualified personnel [13,14,25], and the top management has been scarcely studied as a critical element of corporate innovation. This study establishes the negative impact of air pollution on corporate innovation and verifies the mediating role played by the top management team as a necessary countermeasure to the brain drain effect of air pollution. This is the first time that the quality of the top management has been included in the analytical framework considering air pollution and corporate innovation.

Second, it expands the research related to the human capital of corporate management. Corporate innovation is significantly influenced by the level of competence of top management [27]. However, little research exists on the factors influencing the human capital of top management. This study introduces air pollution as an exogenous variable and verifies its negative impact on the quality of corporate top management.

Third, it adds to the literature on talent policy. Air pollution raises the compensation requirements for corporate executives [28,29]. As a result, corporate pay rises to retain talent have undoubtedly exacerbated the crowding out of corporate funds due to pollution treatment and R&D investments. Local government talent policies provide monetary and non-monetary incentives to attract and gather talent [30]. We examine the impact of local government talent initiatives on reducing the negative externalities of air pollution and suggest a viable policy justification.

The remainder of this article is structured as follows. Section 2 reviews the related literature and formulates the research hypotheses. Section 3 presents the research design. Section 4 shows the empirical results. Section 5 describes the analysis of the impact mechanisms. Section 6 outlines the conclusion and future directions.

## 2. Related Literature and Hypothesis Development

### *2.1. Related Literature*

#### 2.1.1. Definition of Top Management Quality

Top management is a particular category of highly qualified people. The upper echelons theory [31] posits that managers' background qualities, including career experience, education, professional background, and other traits, partially influence organizational results, strategic choices, and company performance. Compared to individual executive characteristics, top management team characteristics are more potent in explaining firm performance [32]. Chemmanur and Paeglis [33] first constructed a composite indicator of top management quality. They pointed out that the quality of corporate top management mainly refers to the human and knowledge resources available to the management of a firm (including various dimensions such as education level and relevant work experience). Since then, terms like "management quality", and "top management human capital" have frequently been addressed in research. There has been no consensus in the academic community on a clear definition of top management quality, with each study defining it on a demand basis. Therefore, the existing definitions differ to varying extents.

#### 2.1.2. The Measurement of Top Management Quality

High-quality top management has the advantage of more external resources for the sustained growth of the organization's innovation initiatives [34]. It is critical for realizing multidimensional innovation and the long-term success of firms [35]. In addition, higher-quality top management is more tolerant of failure and more capable of identifying high-quality inventors, and its focus on corporate innovation effectively stimulates firms' innovation performance [36]. However, deteriorating air quality increases their quit rates, as they choose to move or settle in urban areas with superior air quality. Therefore, the loss of and change in executives due to air pollution implies the loss of vital and strategic resources available to the company; that is, a reduction in the quality of the top management may harm the company's innovation activities. What specific elements are included in the measurement of top management quality is highly subjective, and to address this issue, this study selects a variety of critical executive background characteristics related to innovation performance in the existing literature, which includes having a doctoral degree, overseas background, academic background, financial background, professional background, holding multiple positions, and senior management experience. Based on the above dimensions, this study develops a comprehensive indicator, "Top Management Quality (TMQ)", using principal component analysis to investigate its function in the connection between corporate innovation and air pollution.

### *2.2. Hypothesis Development*

#### 2.2.1. Air Pollution and Corporate Innovation

Innovation is the entrepreneur's recombination of production factors, which can effectively enhance an enterprise's core competitiveness. This can help increase the value of the enterprise value and realize its long-term development. However, air pollution can significantly inhibit the capacity of a town or area to attract or gather key production factors such as people, goods, and capital. This inhibitory effect is further transmitted to enterprises in the region, hindering innovative activities and performance. At the regional level, Zhu and Lee [37] use a dynamic panel model to portray the geographical relationship between provincial innovation and PM2.5 emissions. They found that PM2.5 emissions inhibit local firms' innovation. Moreover, PM2.5 emissions in neighboring regions also inhibit local innovation; that is, there exists a cascading effect of air pollution on the innovation space.

Using provincial-level panel data in China from 1998 to 2018, Zhu et al. [38] discovered that air pollution has a considerable impact on the physical and mental health of R&D staff, weakens the innovation vitality of the region in which they work, and has a gravely detrimental effect on local creativity. Because of air pollution, inventors at companies move to places with superior air quality [39], reducing firms' human capital accumulation and thus inhibiting their innovation output [40].

The principal mechanisms through which air pollution inhibits corporate innovation are the crowding-out and brain drain effects. The term "crowding-out effect" describes how air pollution drives up the cost of environmental management for businesses and reduces their investment in R&D, reducing firms' innovation inputs and outputs. With the increasing public attention on environmental quality, many local governments have begun to urge polluting enterprises to carry out cleaner production, which will undoubtedly increase the cost of environmental management [41,42]. In the meantime, business workers view environmental quality as an increasingly important non-financial gain [28], and some firms prevent brain drain through increasing investment into health insurance for corporate employees and paying additional air pollution allowances [43]. Therefore, under the condition that firms have limited funds, air pollution takes up a large amount of firms' funds to meet environmental regulations or to prevent brain drain, and firms' resources to support other activities, especially R&D, are constrained [44], reducing firms' innovation performance. For example, innovation is negatively affected when firms face stricter environmental regulations [45].

According to the brain drain effect, people who experience physical and mental health problems as a result of air pollution move to areas with cleaner air [16,17]. First, air pollution impairs the physiological functions, cognitive abilities, and mental health of residents [2,40,46,47], which in turn impairs the human capital of firms input quality, reducing individual productivity [12] and inhibiting individual innovation dynamism [13,14]. Second, and more importantly, air pollution-induced brain migration reduces firms' human capital stock and, as a result, hinders firms' innovation. Health problems associated with air pollution increase migrants' health expenditures [18], which in turn drives adaptive behaviors and thus increases the propensity of residents to migrate [19,20] and seek job opportunities in regions with cleaner air. Chu et al. [22] found that people are willing to pay to breathe fresh air and maintain good health to lower air pollution and raise air quality. People are, therefore, susceptible to air pollution, and, in places where air pollution is more prevalent, brain drain is more severe [48]. Wang et al. [23] built an equilibrium model based on cross-country data from China and India to show that there are significant regional differences in the impact of air pollution on the stock of technologically innovative talent. Lai et al. [20] found that the likelihood of college graduates leaving their current city increases by 10% for every 10-unit increase in the concentration of PM2.5. Similarly, the effect of air pollution on the willingness to emigrate increases as the level of education increases [19]. Thus, air pollution inhibits human capital formation and makes people more willing to move to less polluted locations [49]. In particular, highly skilled labor will be more sensitive to air quality [21,23]. As a result, air pollution leads to a decline in firms' human capital stock and hinders firms' innovation [25]. Therefore, Hypothesis 1 is proposed based on the combination of the above two influence effects:

**Hypothesis 1.** *The more severe the air pollution in the location of the enterprise, the lower the enterprise's innovation level.*

#### 2.2.2. Air Pollution and Top Management Quality

The inflow of human capital increases enterprises' human capital, reduces innovation costs, and improves innovation efficiency [29]. However, most current research on human capital migration due to air pollution focuses on skilled human capital, the general labor force, or the employment of college students [20]. The upper echelons theory [31] states that managers' background traits, including career experience, educational attainment, professional background, and other traits, influence organizational outcomes, strategic decisions, and levels of firm performance. While the human capital of both managers and employees is essential for implementing innovation, the human capital of senior managers, in other words, the top management quality, is the most critical factor in realizing multidimensional innovation and long-term business success [35]. According to Maslow's Hierarchy of Needs theory, after an employee's basic physiological needs are met, they will focus on their safety needs. Suppose the health damage and disease risks associated with air quality are not compensated. In that case, the probability of employee turnover increases under the benefit–cost game [50], especially for highly educated, highly skilled, and highly paid employees. It has been shown that CEOs and regular staff have rather different needs for air quality [21,23]. Executives generally have higher levels of education and competence, have more options and job alternatives, and are better able to bear the costs and economic consequences of switching jobs when facing the hazards of air pollution. Cleaner air happens to be a very important non-monetary benefit for corporate executives [28], and air pollution increases the likelihood of executive turnover [51].

It has been widely recognized that the quality of the executive team mainly refers to the existing human and knowledge resources of the enterprise's management, including various dimensions such as education and relevant work experience. There are three possible ways in which air pollution may affect the caliber of the company's leadership team.

First, air pollution directly affects the physiological and psychological health of individual executives, increases the cost of living for executives, and promotes the departure of executives from corporate locations with poor air quality. This is the voluntary turnover of the top management's pre-existing human capital reserves. On one hand, the existing literature shows that air pollution can directly jeopardize human health and cause related diseases. Levine et al. [52] found that toxic plant openings accelerated the rate at which executives left geographically close firms in favor of geographically distant, less polluting firms. Executive worries about the health risks associated with prolonged exposure to bad air quality became more pronounced with longer executive employment, according to the research of Zhu et al. [51], who indicated that low regional air quality significantly increased executive turnover. For this reason, executives may decide to relocate to places with better air quality and leave high-pollution areas in order to escape the detrimental impacts of bad air quality on their health.

On the other hand, executives' cost of living includes both direct and indirect costs. The direct costs are manifested in the increase in medical expenditures due to the health problems associated with higher levels of air pollution. Indirect costs are reflected in the preventive measures taken against air pollution, such as the purchase of masks and air purifiers, as well as expenditures on purchasing commercial medical insurance and commercial health insurance [53,54]. Thus, air pollution promotes increased healthcare expenditures for executives, increasing their cost of living and causing them to leave business locations with poorer air quality.

Second, executives' human capital may involuntarily change as a result of air pollution. Executives move across regions as a result of poor regional air quality as it also has a detrimental impact on business performance [48] and because executives may be fired for performing poorly [55].

Third, air pollution will prevent fresh talent from entering businesses, meaning that there is no practical way to improve the caliber of senior management. On one hand, air pollution makes employers less appealing to prospective employees and influences college students' decisions about where to further their careers [56]; on the other hand, from the standpoint of job applicants, the negative impacts of air pollution on physical and mental health will lead them to select companies with better air quality. However, due to the extreme air pollution in the location where the company is located, the executives must receive greater remuneration from the company [28,29]. This means that firms' return on investment in human capital will decrease, leading to the possibility that they may be reluctant to invest in human resources. The above two factors may result in the quality of corporate top management remaining relatively low due to the lack of effective human resource supplementation. On this basis, Hypothesis 2 is proposed:

**Hypothesis 2.** *The more severe the air pollution in the location of the enterprise, the lower the quality of corporate top management.*

#### 2.2.3. The Mediating Role of Corporate Top Management Quality

The quality of corporate top management is primarily determined by the company's existing human and knowledge resources. The loss and replacement of executives as a result of air pollution represent a loss of vital and strategic resources for the company and may impede the company's innovation activities. Initially, the firm's innovation activities are more likely to be developed over the long term when high-quality senior management has access to a greater number of external resources. Given the information asymmetry of external investors, firms may face difficulties in raising funds for their innovative activities. At the same time, a high-quality top management team has the advantage of more resources outside the company, which might lessen the level of information asymmetry that exists between stock market investors and the company [33], thus easing the financial constraints of the business, which is conducive to the organization's innovative activities in the long run [34].

Second, high-quality top management with highly specialized skills, advanced management experience, and innovation capabilities are more resilient to failure and are better able to predict the future value of innovation investment possibilities. Executives with technical and R&D backgrounds tend to make investments in scientific products and technological innovations more often [57]. They also help managers to identify long-term growth opportunities related to innovation investment and risk-taking levels, provide managers with direct and effective guidance in management decisions on R&D and innovation, and can better achieve the optimal allocation of resources [27]. Meanwhile, high-quality top management is more capable of identifying high-quality inventors, and their focus on corporate innovation will effectively stimulate firms' performance in innovation [36].

Furthermore, the brain drain and turnover of executives triggered by air pollution will also exacerbate the rotation of other employees, thereby undermining the organizational structure's stability [51] and giving rise to recruitment challenges for firms [20]. This will undoubtedly negatively affect corporate innovation.

Lin et al. [58] discovered a substantial relationship between the firm's innovation performance and the political affiliation, professional background, and educational attainment of the CEO using data from the World Bank's study on private manufacturing enterprises. According to Zhao et al. [59], management teams with higher standards typically apply for more patents of a higher caliber, and invest more in research and development projects. In general, executive brain drain, the influx of additional executive human capital, and the general decline in the caliber of the top management team are all impacted by air pollution. As a result, a company's top management will be of higher caliber in cities with superior air quality, which will encourage the company to innovate. Based on this, the following hypothesis is proposed:

**Hypothesis 3.** *Corporate top management quality mediates the relationship between air pollution and corporate innovation.*

#### 2.2.4. The Moderating Role of Local Government Talent Policy

Air pollution raises firms' environmental management costs and crowds out firms' R&D investment, while firms need to pay additional premiums to executives to compensate for the adverse impacts of air pollution on their physical and mental health, which leads to a reduction in firms' innovation inputs and outputs. However, existing studies have neglected the role of local government talent policies. In recent years, through various types of subsidies given directly to talent, local governments' talent policies have not only enhanced the expected reward and attractiveness of talent to work in the local area but have also promoted the spillover effect of innovation factors. First of all, the government's talent policy can effectively reduce the hiring cost of talent to a certain extent. More talents seek jobs locally, which increases the supply of talent in local areas, and the competition among talents leads to lower costs for enterprises to recruit. Besides direct monetary subsidies, the government's talent policy also grants excess earnings or non-monetary benefits in terms of household registration, housing, and children's education. This improves the bargaining power of local firms, increases the recruitment of relevant and innovative talent [30], helps to attract and retain senior management and technical talent, and enhances the quality of the top management.

In addition, the talent aggregation effect can bring about the rapid flow of information, which helps to produce information sharing, collective learning, knowledge spillover, and other clustering effects among groups of high-tech talents [60,61], which enhance the quality of top management. Effective talent policy can attract and gather more high-level talents. When the talent aggregation of enterprises reaches a certain level, it will drive the innovation factors to produce spillover effects, form a more favorable innovation atmosphere (which is conducive to the skills improvement and knowledge exchange among the top management members), and enhance the innovation ability and output efficiency of enterprises [30]. Second, from the perspective of signaling theory, the talent policy signal transmitted by local enterprises through the "endorsement" of talent policy is conducive to enterprises' proximity to government resources and promotes the development of enterprise innovation activities. Talent support from local governments can alleviate information asymmetry. This is conducive to improving the commercial credit of enterprises, which helps to alleviate resource constraints and promote the innovation of enterprises [30].

In summary, a positive correlation exists between innovation inputs (such as talent) and outputs [27]. Therefore, local government talent policy can reduce the hiring cost of enterprises, promote the concentration of more innovation factors in the region, and provide government "endorsement" to stakeholders, thus reducing the adverse impact of air pollution on enterprise innovation to a certain extent. Accordingly, Hypothesis 4 is proposed:

**Hypothesis 4.** *Local government talent policies will negatively moderate the relationship between air pollution and corporate innovation.*

The above theoretical assumptions are demonstrated in Figure 1.

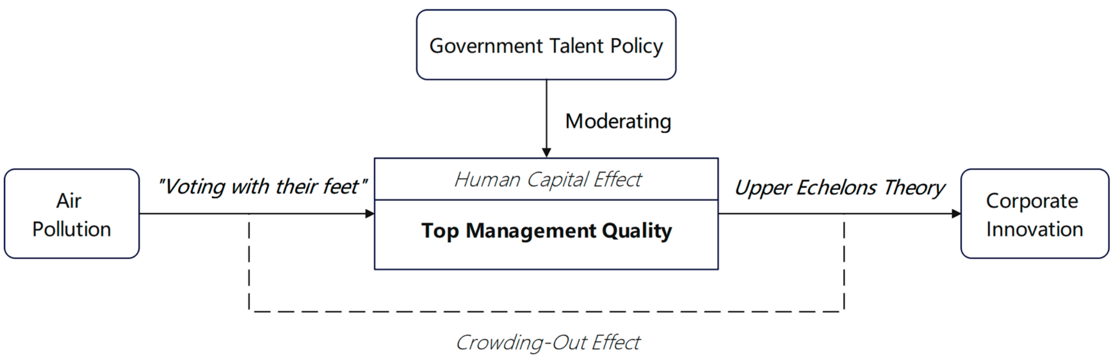


**Figure 1.** The theoretical framework.

## 3. Research Design

### *3.1. Sample Selection and Data Sources*

We used all Chinese A-share listed companies from 2004 to 2019 as the initial sample (Considering the relevant data currently published by China Meteorological Network is as of 2019, and there are more missing values in the relevant databases, the data from

2004–2019 were selected to ensure the reliability of the results). The data were screened according to the following criteria: (1) companies with delisting treatment such as ST, PT, and ST*, among others, and located in cities with incomplete PM2.5 data were excluded; (2) financial companies in sectors such as banking, insurance, and securities; those with missing and abnormal patents, financial, R&D and manager data; or with the total number of patent applications less than 1 were excluded, and (3) all continuous variables were winsorized at the level of 1%. After the above screening steps, the sample obtained comprised 3088 listed companies with 13,654 firm-year observations.

The CSMAR database (China Stock Market & Accounting Research Database) provides basic information about listed companies, financial data, and data for constructing the top management quality indicators. The data for PM2.5 and AQI indices were collected from the CNRDS (Chinese Research Data Services Platform) and the official website of China's Ministry of Ecology and Environment. Patent applications, patents granted, and R&D investment data were all sourced from the CNRDS. Local governments' talent policy data were manually collected from each local government's annual work report.

### *3.2. Definition of Variables*

#### 3.2.1. Explanatory Variables

Air Pollution (*LnPM*). Referring to Van et al. [62], the annual average PM2.5 concentration value at the city level were selected as the core indicator based on careful consideration of air pollution data's availability, objectivity, and reliability. In order to match the data of companies and cities, we first collected the office address information of listed companies from the CSMAR database. Then we matched it to the city's air pollution indicator (PM2.5). The city's PM2.5 concentration was measured by taking the natural logarithm.

#### 3.2.2. Explained Variables

Three indicators are used to represent the innovation level of enterprises, including the number of patent applications (*PatentApply*), the number of patents granted (*PatentGrant*), and the intensity of R&D investment (*RD-Ratio*). Among them, the number of patents applied for and granted represents the R&D output (We take the natural logarithm of the number of patent applications plus 1 and the number of patents granted plus 1, respectively. To avoid the influence of extreme values on the results, the variable of the number of patent applications was winsorized by winsor2; that is, it was truncated at the upper and lower 1% quartiles, and the natural logarithm was taken by adding 1 to the truncated value), and the R&D investment intensity represents the R&D input (The time frame for this analysis was 2007–2019, as R&D investment data for Chinese listed companies have been published since 2007) (R&D expenditure/total assets). We adopted an integrated perspective of R&D outputs and inputs to measure firms' innovation level, in order to better ensure the robustness of the findings.

#### 3.2.3. Mediating Variables

Top Management Quality (TMQ). Referring to Chemmanur & Paeglis [33] and Chemmanur et al. [27], and combining the information on top managers disclosed in the annual reports of each company, we define as managers with a title of division director or higher. The senior managers in our sample can be broadly categorized in seven groups: CEOs, presidents, board members, other chief officers (CFO, etc.), division heads, VPs, and others. In detail, we include board members who hold positions of authority, supervisory board members, presidents, vice presidents, general managers, deputy general managers, financial directors, technical directors, chief executive officers, chief financial officers, chief economists, secretaries of boards of directors, and secretaries of party committees. Under our research scenario, we selected well-validated top managerial characteristics that significantly affect innovation activities, including the education level [58,63,64], overseas experience [7,65], academic background [66], financial background [67,68], professional background [69,70], holding of multiple positions [71–73] and executive career experience [36].

Based on this, we first constructed the following seven sub-indicators: *PhD* (the number of corporate managers who have obtained a doctoral degree); *Overseas* (the number of corporate managers with overseas study or work experience); *Academic* (the number of corporate managers with an academic background); *Fin* (the number of corporate managers with a financial background); *Profession* (the number of corporate managers in the production, operation, R&D, sales or finance function in the management team); *Higher* (the number of managers who hold the position of vice chairman or vice general manager and higher positions); and *Exp* (the number of managers who held the position of CEO, CFO, vice director or above in other companies before joining the company). The above seven sub-indicators were adjusted, and three common components were extracted using principal component analysis with a KMO (Kaiser Meyer Olkin) value of 0.681 to obtain the following Equation (1).

$$TMQ = 0.123 * PhD + 0.160 * Overseas + 0.087 * Academic + 0.180 * Fin + 0.156 * Profession + 0.067 * Higher + 0.028 * Exp \quad (1)$$

Thus, higher TMQ scores reflect the higher quality of top management human capital, where *PhD*, *Overseas*, *Academic*, *Fin*, *Profession*, *Higher*, and *Exp* are standardized data.

#### 3.2.4. Moderating Variables

Local Talent (*LT*), the local government's attention to scientific and technological talents, was selected as a proxy variable for the intensity of talent policies implemented by prefecture-level city governments. First, the Local Government Work Reports (including 274 prefecture-level cities of 31 provinces) from 2008 to 2019 were collected manually. Second, the frequency of the occurrence of words related to science and technology talents was counted via word segmentation of the government report texts, and the frequency was taken as the natural logarithm. The related words are talent resources, high-level talents, talent team formation, leading talents, scientific and technological innovation and so on.

#### 3.2.5. Control Variables

Based on existing studies, we selected control variables at both the firm and city levels. At the firm level, we controlled for firm size, age, nature of property rights, profitability, asset–liability ratio, current asset ratio, capital intensity, and social wealth creativity. At the city level, we controlled for the share of the second industrial output value in the GDP of the host city, foreign investment, the GDP of the host city, the GDP per capita of the city, the average annual sunshine hours of the city and the average annual temperature of the city. The specific definitions of the variables are provided in Table 1, and the results of the correlation analysis are outlined (see Appendix A).

### *3.3. Empirical Model*

#### 3.3.1. OLS Regression Models

We first used ordinary least squares (OLS) to estimate the impact of air pollution on the corporate innovation of listed companies, and the regression model is as follows:

$$PatentApply_{i,c,t} / PatentGrant_{i,c,t} / RD\_Ratio_{i,c,t} = \beta_0 + \beta_1 LnPM_{i,c,t} + \beta X_{i,c,t} + \gamma_t + \rho_r + \varepsilon_{i,c,t} \quad (2)$$

where $i$ represents enterprise; $c$ represents city; $t$ represents time. $PatentApply_{i,c,t}$, $PatentGrant_{i,c,t}$ and $RD\_Ratio_{i,c,t}$ are the indicators to measure the level of innovation of the firms, $X_{i,c,t}$ is a series of control variables affecting firms' innovation in year $t$ of company $i$. $\gamma_t$ and $\rho_r$ represent the fixed effects of the year and the industry, respectively; $\varepsilon_{i,c,t}$ represents the standard error term; and the coefficient $\beta_1$ measures the impact of air pollution on firms' innovation level.

**Table 1.** Variable definitions.

| Symbol | Variable Name | Variable Description |
|---|---|---|
| Explanatory variable | | |
| PM2.5 | PM2.5 concentration | The annual average concentration of PM2.5 emitted by prefecture-level and larger cities in natural logarithm (μg/m$^3$) |
| Explained variable | | |
| PatentApply | Number of patent applications | Natural logarithm of the number of patent applications filed in the year plus one |
| PatentGrant | Number of patents granted | Natural logarithm of the number of patents granted in the year plus one |
| RD_ratio | R&D investment intensity | Enterprise R&D expenditure/total enterprise assets (%) |
| Mediating variable | | |
| TMQ | Quality of corporate top management team | Principal component analysis by 7 indicators: PhD, Overseas, Academic, Fin, Profession, Higher, and Exp |
| Moderator variable | | |
| LT | Local government talent attention | Frequency of S&T talent-related terms in the government work reports of prefecture-level cities in natural logarithm |
| Control variables (firm-level) | | |
| Capital | Capital intensity | Total business assets/operating income (%) |
| Leverage | asset-liability ratio | Total liabilities/total assets of the enterprise (%) |
| TobinQ | Social wealth creativity | Enterprise Tobin's Q expressed as enterprise market capitalization/(total assets and—net intangible assets—net goodwill) (%) |
| Liquidity | Current assets ratio | Total enterprise current assets/total assets (%) |
| ROA | Profitability | Return on assets expressed as net profit at the end of the period/total assets at the end of the period (%) |
| LnSale | Enterprise size | The total assets of the enterprise at the end of the period are expressed in natural logarithms (CNY) |
| LnAge | Number of years in the company | Natural logarithm of (year of company—year of listing) (year) |
| BoardIndSize | Size of independent directors | The proportion of independent directors to the total number of board members (%) |
| Control variables (city-level) | | |
| Structure | Industrial structure | Share of secondary industry in GDP of the city where the enterprise is located (%) |
| FDI | Foreign investment | Share of the amount of foreign capital actually utilized in the city where the enterprise is located in the current year as a percentage of GDP (%) |
| GDP | City-year GDP | The annual GDP of the city where the enterprise is located is taken as a natural logarithm (billion CNY) |
| GDPAvg | Annual urban GDP per capita | Average annual city GDP divided by total city population in natural logarithms (million CNY) |
| Suntime | Annual sunshine hours in cities | Average annual sunshine hours in the city (hours) |
| Temperature | Average annual temperature values for cities | Average annual urban air temperature values (°C) |

Data source: Monthly climate data for cities and counties were obtained from the China Meteorological Data Network.

### 3.3.2. Mediating Effects

Referring to Alesina et al. [74], we used a mediator model to analyze the mechanism of air pollution's impact on firms' innovation; that is, the mediating role of the top management quality. The following model is developed:

$$LnPM_{i,c,t} = \eta_0 + \omega_1 Inversion_{i,c,t} + \omega X_{i,c,t} + \gamma_t + \rho_r + \varepsilon_{i,c,t} \quad (3)$$

$$TMQ_{i,c,t} = \lambda_0 + \lambda_1 LnPM_{i,c,t} + \lambda X_{i,c,t} + \gamma_t + \rho_r + \varepsilon_{i,c,t} \quad (4)$$

$$PatentApply_{i,c,t}/PatentGrant_{i,c,t}/RD\_Ratio_{i,c,t} = \mu_0 + \mu_1 LnPM_{i,c,t} + \delta TMQ_{i,c,t} + \theta X_{i,c,t} + \gamma_t + \rho_r + \varepsilon_{i,t} \quad (5)$$

Model (3) is the first-stage regression model of the instrumental variable approach; $LnPM_{i,c,t}$ is the logarithm of the annual average PM2.5 concentration in year $t$ of the city $c$

where company $i$ is located; and the instrumental variable $Inversion_{i,c,t}$ is the logarithm of the number of days of atmospheric inversion in the city where company $i$ is located, after adding 1.

Model (5) is a second-stage regression model, where the dependent variables $PatentApply_{i,c,t}$, $PatentGrant_{i,c,t}$ and $RD\_Ratio_{i,c,t}$ are measures of firms' level of innovation; $X_{i,c,t}$ is a series of control variables affecting firms' innovations in year $t$; $\gamma_t$ and $\rho_r$ represent year and industry fixed effects, respectively; $\varepsilon_{i,c,t}$ represents the standard error term; and we focus on the coefficients $\lambda_1$, $\mu_1$, and $\delta$.

3.3.3. Moderating Effect

In order to examine the moderating effect of local government talent attention on air pollution and firms' innovation, we set up the following model (6):

$$PatentApply_{i,c,t}/PatentGrant_{i,c,t}/RD_{Ratio\,i,c,t} = \alpha_0 + \alpha_1 LnPM_{i,c,t} + \alpha_2 LnPM_{i,c,t} * LT_{i,c,t} + \alpha_3 LT_{i,c,t} + \alpha X_{i,c,t} + \gamma_t + \rho_r + \varepsilon_{i,c,t} \tag{6}$$

where $LT_{i,c,t}$ is the intensity of local talent policy; $LnPM_{i,c,t} * LT_{i,c,t}$ is the interaction term between air pollution and local talent policy; and the meanings of the other variables are consistent with the above models.

## 4. Empirical Results and Endogeneity Test

### *4.1. Descriptive Statistics*

Table 2 lists the descriptive statistics of the core variables. It can be seen that the standard deviation of the annual number of patent applications is 1.276 and the number of patents granted is 1.410, indicating that there is a great difference in innovation output among enterprises. The standard deviation of the PM2.5 concentration in the city where the company's office is located is 0.332 μg/m$^3$, indicating that there is a great difference in the degree of air pollution in various cities. In addition, we also carried out the variance inflation factor (VIF) test for all variables, and the average VIF value is less than 2, indicating that there is no serious multicollinearity between the variables.

**Table 2.** Descriptive statistics of core variables.

| Variables | Observed | Average | S.D. | Min | Max |
|---|---|---|---|---|---|
| PatentApply | 13.654 | 2.933 | 1.276 | 0.693 | 6.687 |
| PatentGrant | 13.654 | 2.482 | 1.410 | 0.000 | 8.354 |
| RD_Ratio | 10.592 | 0.022 | 0.017 | 0.000 | 0.098 |
| LnPM | 13.654 | 3.655 | 0.320 | 2.636 | 4.280 |
| TMQ | 8.165 | −0.010 | 0.540 | −1.094 | 3.694 |
| Capital | 13.654 | 2.142 | 1.413 | 0.425 | 9.189 |
| Leverage | 13.654 | 0.410 | 0.200 | 0.053 | 0.881 |
| Liquidity | 13.654 | 0.585 | 0.186 | 0.122 | 0.941 |
| TobinQ | 13.654 | 1.955 | 1.100 | 0.881 | 7.009 |
| ROA | 13.654 | 0.043 | 0.054 | −0.200 | 0.191 |
| LnSale | 13.654 | 21.320 | 1.378 | 11.60 | 28.720 |
| LnAge | 13.654 | 1.858 | 0.905 | 0.000 | 3.258 |
| BoardIndSize | 13.654 | 0.372 | 0.052 | 0.308 | 0.571 |
| FDI | 13.654 | 0.0272 | 0.0168 | 0.001 | 0.080 |
| Structure | 13.654 | 45.150 | 10.620 | 16.200 | 65.590 |
| GDP | 13.654 | 8.555 | 1.047 | 5.974 | 10.470 |
| GDPAvg | 13.654 | 2.035 | 0.755 | −3.814 | 3.845 |
| Suntime | 13.654 | 1911 | 332.700 | 1068 | 3055 |
| Temperature | 13.654 | 16.510 | 3.854 | 3.685 | 24.510 |

### *4.2. Empirical Results and Analysis*

Table 3 reports the regression results of model (1) Columns (1), (2), and (3) demonstrate the results of the baseline regression, which includes only all the control variables. Columns (4), (5), and (6) demonstrate the regression results that incorporate the core explanatory variables, and the coefficients of all explanatory variables are negatively significant at a 1%

level, which indicates that there is a significant and negative impact of air pollution on the innovation of the firms. This empirical finding is in line with a series of studies conducted in the United States [75], the European region [76], and BRICS countries [23,24,40], which revealed that air pollution has a negative impact on innovation activities. Therefore, Hypothesis 1 is confirmed.

**Table 3.** Impact of air pollution on corporate innovation.

| Variable | (1) PatentApply | (2) PatentGrant | (3) RD_Ratio | (4) PatentApply | (5) PatentGrant | (6) RD_Ratio |
|---|---|---|---|---|---|---|
| LnPM | | | | −0.6320 *** | −0.4689 *** | −0.0035 *** |
| | | | | (0.0710) | (0.0831) | (0.0011) |
| Capital | 0.1021 *** | 0.0893 *** | −0.0030 *** | 0.1010 *** | 0.0885 *** | −0.0030 *** |
| | (0.0158) | (0.0135) | (0.0003) | (0.0158) | (0.0137) | (0.0003) |
| Leverage | −0.1780 ** | −0.1880 * | −0.0080 *** | −0.1747 ** | −0.1856 * | −0.0080 *** |
| | (0.0807) | (0.0973) | (0.0019) | (0.0786) | (0.0967) | (0.0020) |
| Liquidity | 0.1318 | 0.1551 | 0.0035 | 0.1313 | 0.1548 | 0.0035 |
| | (0.1241) | (0.1321) | (0.0033) | (0.1213) | (0.1313) | (0.0033) |
| TobinQ | 0.0191 | 0.0150 | 0.0023 *** | 0.0190 | 0.0149 | 0.0023 *** |
| | (0.0176) | (0.0169) | (0.0005) | (0.0169) | (0.0166) | (0.0005) |
| ROA | 0.6247 ** | −0.1203 | 0.0112 * | 0.6286 ** | −0.1174 | 0.0112 * |
| | (0.2643) | (0.2909) | (0.0067) | (0.2636) | (0.2955) | (0.0066) |
| LnSale | 0.4996 *** | 0.5160 *** | 0.0002 | 0.4974 *** | 0.5144 *** | 0.0002 |
| | (0.0398) | (0.0459) | (0.0006) | (0.0393) | (0.0456) | (0.0006) |
| LnAge | 0.0340 | 0.0218 | −0.0015 *** | 0.0356 | 0.0230 | −0.0015 *** |
| | (0.0252) | (0.0275) | (0.0004) | (0.0250) | (0.0272) | (0.0004) |
| BoardIndSize | −0.0198 | 0.1617 | −0.0022 | −0.0122 | 0.1673 | −0.0021 |
| | (0.2357) | (0.3001) | (0.0050) | (0.2277) | (0.2969) | (0.0050) |
| FDI | 0.2014 | 1.3752 | 0.0041 | 0.8710 | 1.8720 | 0.0057 |
| | (1.1480) | (1.2594) | (0.0171) | (0.9470) | (1.1585) | (0.0162) |
| Structure | 0.0050 | 0.0030 | 0.0000 | 0.0036 | 0.0020 | 0.0000 |
| | (0.0031) | (0.0041) | (0.0001) | (0.0035) | (0.0038) | (0.0001) |
| GDP | 0.3292 *** | 0.2525 ** | 0.0049 ** | 0.2659 ** | 0.2055 * | 0.0045 ** |
| | (0.1062) | (0.1045) | (0.0022) | (0.1045) | (0.1078) | (0.0020) |
| GDPAvg | −0.0248 | −0.0409 | −0.0003 | −0.0380 | −0.0507 * | −0.0004 |
| | (0.0229) | (0.0256) | (0.0004) | (0.0236) | (0.0264) | (0.0004) |
| Suntime | −0.0001 | 0.0000 | 0.0000 | −0.0000 | 0.0001 | 0.0000 |
| | (0.0001) | (0.0002) | (0.0000) | (0.0001) | (0.0002) | (0.0000) |
| Temperature | 0.0579 | 0.0703 | −0.0002 | −0.0211 | 0.0117 | −0.0007 |
| | (0.0819) | (0.0649) | (0.0009) | (0.0472) | (0.0466) | (0.0007) |
| Constant | −11.9053 *** | −12.3207 *** | −0.0205 | −7.7149 *** | −9.2119 *** | 0.0043 |
| | (2.0912) | (1.8980) | (0.0291) | (1.8397) | (2.0346) | (0.0226) |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes |
| City | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 13,654 | 13,654 | 10,592 | 13,654 | 13,654 | 10,592 |
| $R^2$ | 0.474 | 0.465 | 0.450 | 0.477 | 0.466 | 0.451 |

Note: *t*-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

### 4.3. Endogeneity Test

Although we included many control variables in the estimation of model (1) to minimize the omitted variable problem, there may still be an endogeneity problem due to reverse causality between air pollution and firm innovation. Therefore, drawing on Arceo et al. [77], we used the natural logarithm of the number of days per year that an atmospheric inversion occurs in the city where each firm's office is located plus 1 as an instrumental variable for air quality. The results show that, in the first-stage regression, atmospheric inversion has a significant positive effect on air pollution (i.e., atmospheric inversion significantly increases the degree of air pollution), with an F-value much larger than 10. In the second-stage regression results, the coefficients of LnPM are all negatively correlated at a significance level of 1%, (i.e., air pollution is still significantly negatively related to enterprise innovation). The results are reported in Table 4.

**Table 4.** Regression results of the instrumental variable method.

| | PatentApply | PatentGrant | RD_Ratio |
|---|---|---|---|
| LnPM | −0.4849 *** | −0.3786 *** | −0.0082 *** |
| | (0.1225) | (0.1378) | (0.0023) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 13,654 | 13,654 | 10,592 |
| $R^2$ | 0.443 | 0.434 | 0.396 |

Note: *t*-values in parentheses, *** $p < 0.01$.

## 5. Mechanism Test Based on Top Management Quality and Local Talent Policy

### *5.1. The Mediating Role of Corporate Top Management Quality (TMQ)*

In the above empirical analysis, the inhibitory effect of air pollution on corporate innovation was been verified. Next, we tested the impact mechanism. In the hypothesis development section, we pointed out that air pollution will reduce the top management quality of enterprises, thus adversely affecting the innovation of enterprises. First, we verified the negative correlation between air pollution and top management quality. Firms with poorer quality top management may be more reluctant to take on corporate social responsibility and neglect environmental issues. This may exacerbate the endogeneity problem of air pollution in the region. We used the instrumental variable (*Inversion*) from the previous endogeneity test to conduct an instrumental variable two-stage regression. Table 5 reports the results of the OLS regression and the 2SLS regression. In the basic regression in column 1, the coefficient of *LnPM* is −0.0819 and significant at the 1% level, indicating that air pollution significantly reduces top management quality. In the second stage of regression of instrumental variables, the coefficient of air pollution *LnPM* is significantly negative at a 5% level. This indicates that the more severe the air pollution, the poorer the quality of corporate top management. The regression results further demonstrate that air pollution has a significant negative impact on the quality of top management. Therefore, Hypothesis 2 is confirmed.

**Table 5.** Regression results of air pollution and top management quality.

| Variable | (1) OLS<br>TMQ | (2) 2SLS<br>TMQ |
|---|---|---|
| LnPM | −0.0819 *** | −0.2185 ** |
| | (0.0259) | (0.0989) |
| Controls | Yes | Yes |
| Year | Yes | Yes |
| Industry | Yes | Yes |
| N | 8165 | 8165 |
| $R^2$ | 0.354 | 0.269 |

Note: *t*-values in parentheses, ** $p < 0.05$, and *** $p < 0.01$.

Next, according to Alesina et al. [74], we tested the mediating effect of the quality of top management. The results are reported in Table 6. In Column (1), the coefficient of air pollution (*LnPM)* on the number of patent applications is −0.2794, and on the number of granted patents is −0.1714, which is significant at a 1% level. The coefficient of R&D investment is −0.0015, which is negatively significant at a 5% level. This confirms that air pollution can directly reduce enterprise innovation. Meanwhile, in the 2SLS regression of column (3), the coefficients between air pollution and corporate innovation are also all negative and significant. However, the absolute value of the coefficients −0.6485, −0.7569, and −0.0075 are larger than the OLS regression results. This may be due to the elimination of the endogeneity issue brought by air pollution.

**Table 6.** The mediating effect of top management quality.

| Variable | (1) OLS | (2) OLS | (3) 2SLS | (4) 2SLS |
|---|---|---|---|---|
| Panel A | | PatentApply | | |
| LnPM | −0.2794 *** | −0.2680 *** | −0.6485 *** | −0.5900 *** |
| | (−5.2704) | (−5.0753) | (0.1841) | (0.1834) |
| TMQ | | 0.1477 *** | | 0.2677 *** |
| | | (6.4172) | | (0.0228) |
| Controls | YES | YES | YES | YES |
| Year | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| N | 8165 | 8165 | 8165 | 8165 |
| $R^2$ | 0.322 | 0.321 | 0.437 | 0.448 |
| Panel B | | PatentGrant | | |
| LnPM | −0.1714 *** | −0.1593 *** | −0.7569 *** | −0.6968 *** |
| | (0.0600) | (0.0598) | (0.2080) | (0.2077) |
| TMQ | | 0.1567 *** | | 0.2752 *** |
| | | (0.0260) | | (0.0269) |
| Controls | YES | YES | YES | YES |
| Year | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| N | 8165 | 8165 | 8165 | 8165 |
| $R^2$ | 0.294 | 0.294 | 0.420 | 0.430 |
| Panel C | | RD_Ratio | | |
| LnPM | −0.0015 ** | −0.0015 ** | −0.0075 ** | −0.0071 ** |
| | (0.0007) | (0.0007) | (0.0029) | (0.0029) |
| TMQ | | 0.0001 | | 0.0015 *** |
| | | (0.0003) | | (0.0003) |
| Controls | YES | YES | YES | YES |
| Year | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| N | 7325 | 7325 | 7325 | 7325 |
| $R^2$ | 0.163 | 0.162 | 0.394 | 0.397 |

Note: *t*-values in parentheses, ** $p < 0.05$, *** $p < 0.01$.

In terms of the mediating effect of top management quality, first, it was demonstrated above that the coefficient of top management quality on air pollution is significantly negative at the 1% level, indicating that air pollution in the city where offices are located significantly reduces the quality of top management. Second, in column (2), when air pollution, top management quality, and firm innovation are regressed simultaneously, the OLS regression coefficients of top management quality are 0.1477, 0.1567, and 0.0001. Among the three measures, innovation outputs (i.e., *PatentApply* and *PatentGrant*) are both positively significant at the 1% level. Although the role of top management quality on R&D investment is not significant in the results of the OLS model, in the results of the 2SLS model shown in Column (4), the coefficients of top management quality are all positively significant at the 1% level and the coefficients all increased. Most importantly, the regression coefficients of air pollution all decrease after adding the top management quality, indicating that the top management quality plays a mediating role between air pollution and firm innovation. In summary, air pollution can indirectly reduce innovation output through reducing the quality of top management. The mechanism can be described as "Air pollution–Top management Quality–Corporate Innovation". Hence, Hypothesis 3 is verified.

In addition, to verify the mediating effect's robustness, we also conducted a Sobel test and bootstrap test. The absolute values of the Z-values in the Sobel test were 6.193, 6.09, and 2.524, which are all greater than 1.65, and the *p*-value was also significant at the 1% level. In the bootstrap mediating effect test, the 95% confidence interval estimation contained no 0 after 1000 iterations. This indicates that the mediating effect is significant; that is, there is a significant mediating effect of the top management quality in the relationship between air pollution and corporate innovation.

### *5.2. The Moderating Role of Local Government Talent Policies*

In recent years, China has opened up an inter-regional competition for talent. Almost all major cities have introduced many talent policies, mainly oriented to groups with advanced skills, high education, and high innovation ability. From the perspective of marginal cost, the talent policy reduces the talent hiring cost borne by enterprises to a certain extent and enhances the attractiveness of local enterprises, and is conducive to promoting skills upgrading and knowledge exchanges among the top management team. From the perspective of marginal benefit, attracting and gathering more talent is conducive to creating an atmosphere of innovation factor agglomeration, significantly improves the corporate top management's quality, and enhances the team's innovation ability, which can further improve the innovation efficiency and output of enterprises [30]. Therefore, we tested the moderating effect of local government's talent attention on air pollution and firms' innovation, and the results are reported in Table 7. We can see that the interaction term of *LnPM*LT* is significantly and positively related to the number of patent applications, the number of patents granted, and the intensity of R&D investment at the 1%, 10%, and 5% levels, respectively. This suggests that local talent policy weakens the negative impact of air pollution on firms' innovation, to a certain extent, thus verifying Hypothesis 4.

**Table 7.** The moderating effect of local government talent attention.

| Variable | (1) PatentApply | (2) PatentGrant | (3) RD_Ratio |
|---|---|---|---|
| LnPM | −0.3588 *** | −0.2377 *** | −0.0024 *** |
| | (0.0448) | (0.0503) | (0.0006) |
| LT | −0.0022 | −0.0005 | 0.0003 |
| | (0.0163) | (0.0184) | (0.0002) |
| LnPM*LT | 0.1413 *** | 0.0847 * | 0.0014 ** |
| | (0.0438) | (0.0494) | (0.0006) |
| Controls | YES | YES | YES |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 12023 | 12023 | 9554 |
| $R^2$ | 0.386 | 0.367 | 0.2 |

Note: *t*-values in parentheses, * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

### *5.3. Further Analysis*

Due to the negative externalities of air pollution, governments are increasingly emphasizing the regulatory role of environmental regulation, which can prompt firms to increase their environmental investment in pollution prevention and control [78]. However, this may crowd out firms' R&D investment and inhibit their innovation. Conversely, executives with strong bargaining power and high incomes need higher wages to compensate for the adverse impacts of air pollution on their physical and mental health (i.e., loss of non-monetary earnings). In order to attract and retain talent and maintain a higher level of top management quality, firms need to compensate by paying an additional premium to executives [28,29]. In addition, appropriate compensation can, to a certain extent, mitigate the risk-averse behavior of executives toward innovative activities [79], and, when the CEO compensation structure is linked to stock volatility, it can affect the corporate social responsibility (CSR) performance to a large extent [80]. A reasonable CEO compensation structure will encourage the executive team to invest in innovative projects [81], thereby increasing the team's innovation capability. This is important for the sustainable operation and development of firms. Therefore, we test the moderating effects of local government environmental governance and corporate executive compensation separately in this section.

#### 5.3.1. Government Environmental Protection Attention

Referring to Chen et al. [19], we use local government environmental protection attention (LEP) as a proxy variable for local government environmental governance. We manually collected provincial government work reports (including 31 provinces) from 2008 to 2019. We counted the frequency of environment-related words through applying word segmentation to the government report text (We take the natural logarithm for the word frequency). Compared with other commonly used metrics, LEP is more comprehensive and can better reflect the overall status of local environmental governance. From Table 8, it can be seen that the interaction terms *LnPM*LEP* are all negatively significant at the 1% level, indicating that the government's attention to environmental protection strengthens the negative correlation between air pollution and firms' innovation. This result is consistent with the findings of existing studies.

**Table 8.** The moderating effect of the government's attention to environmental protection.

| Variable | (1)<br>PatentApply | (2)<br>PatentGrant | (1)<br>RD_ratio |
|---|---|---|---|
| LnPM | −0.3369 *** | −0.2076 *** | −0.0012 ** |
| | (0.0426) | (0.0478) | (0.0006) |
| LEP | 0.0615 ** | 0.0833 *** | −0.0003 |
| | (0.0271) | (0.0306) | (0.0004) |
| LnPM*LEP | −0.2590 *** | −0.2383 *** | −0.0032 *** |
| | (0.0761) | (0.0860) | (0.0010) |
| Controls | YES | YES | YES |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 12,829 | 12,829 | 10,200 |
| $R^2$ | 0.376 | 0.362 | 0.169 |

Note: *t*-values in parentheses, ** $p < 0.05$, and *** $p < 0.01$.

#### 5.3.2. Executive Compensation

Next, we measured the executive compensation variable (*Salary*) using the natural logarithm of the total compensation of the top three executives with the highest amount disclosed by listed companies. We tested the moderating effect of executive compensation on the relationship between air pollution and innovation of firms. The results in Table 9 show that the coefficients of the interaction term, *LnPM*Salary*, are significantly positive at the 5%, 10%, and 1% levels, respectively; that is, a firm's executive compensation can recover to a certain extent for the negative impacts of air pollution on a firm's technological innovation.

**Table 9.** The moderating effect of executive compensation.

| Variable | (1)<br>PatentApply | (2)<br>PatentGrant | (3)<br>RD_Ratio |
|---|---|---|---|
| LnPM | −0.3685 *** | −0.2347 *** | −0.0012 ** |
| | (0.0431) | (0.0485) | (0.0006) |
| Salary | 0.0527 *** | 0.0646 *** | 0.0025 *** |
| | (0.0185) | (0.0208) | (0.0003) |
| LnPM*Salary | 0.1018 ** | 0.0764 * | 0.0021 *** |
| | (0.0407) | (0.0460) | (0.0006) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 12,618 | 12,618 | 9992 |
| $R^2$ | 0.394 | 0.377 | 0.177 |

Note: *t*-values in parentheses, * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

*5.4. Robustness Tests*

We conducted a series of tests to ensure the robustness of the benchmark regression results. First, in terms of the explained variables, as an enterprises' innovation output needs a certain period and has a lag, we advanced the number of patent applications and the number of patents granted by 1, 2, and 3 periods. The regression results verify Hypothesis 1 (see Appendix B). In addition, we subdivided the total number of patent applications into the number of invention patent applications (*IPatentApply*) and the number of non-invention patent applications (*UnIPatentApply*) for the OLS regression. The result is consistent with the results of the benchmark regression (see Appendix C).

Second, in terms of the explanatory variables, we replaced the PM 2.5 concentration with the annual average air quality index (AQI) of the city where the company's office is located for robustness testing (the unit is $\mu g/m^3$, and we take the natural logarithm for the AQI). The baseline regression results remained robust (see Appendix D).

Finally, in terms of the selected samples, megacities—including Beijing, Shanghai, Guangzhou, and Shenzhen—have a stronger agglomeration of resources, which leads to a lower comparability of the samples with other cities. Therefore, we used OLS to conduct regression after excluding the samples from Beijing, Guangzhou, and Shenzhen, and Hypothesis 1 was verified again (see Appendix E).

## 6. Concluding Discussion and Policy Implications

*6.1. Concluding Discussion*

This study incorporated the quality of top management and local talent policy into the analytical framework of air pollution and corporate innovation. First, we analyzed the mechanism between air pollution and corporate innovation, and developed relevant hypotheses. Then, we used a sample of Chinese public companies from 2007 to 2019 to analyze the impact of air pollution on corporate innovation. The findings revealed that the more severe the air pollution in a firm's location, the lower its level of innovation, suggesting that air pollution has an inhibiting effect on the innovative activities of local firms. This empirical finding is in line with a series of studies and existing evidence from different regions around the world, including the United States [75], Europe [76], and BRICS countries [23,24,40], which have revealed that air pollution has an adverse impact on innovation activities.

Next, to explore the intrinsic mechanism between air pollution and enterprise innovation, we tested the mediating effect of top management quality and the moderating effect of local talent policy. Based on the theory of "voting with their feet" and the upper echelons theory, we found that the quality of the top management plays a mediating role between air pollution and corporate innovation. It was verified that the brain drain effect caused by air pollution will lead to a decline in corporate innovation. Nevertheless, the moderating effect of local talent policy suggests that local government's attention to talent can alleviate the negative effect of air pollution on corporate innovation. Therefore, enterprises can optimize the top management's structure and improve its quality to promote innovation output. Equally, local governments can improve local talent policies to enhance the supply of high-skilled talent and improve the innovation vitality of local enterprises. The previous literature has mainly focused on the capital crowding-out effect while focusing on the general workgroup regarding the human capital channel [13,14,25]. This study provides novel evidence from the view of top management quality.

In addition, it has been found that air pollution raises the salary compensation requirements of corporate executives, and this study empirically confirmed that executive compensation can mitigate the negative impact of air pollution on firms' innovation. In addition, the increase in the intensity of local environmental regulation and supervision will crowd out firms' R&D investment and reduce their innovation output. Policymakers should also consider cultivating and developing enterprises' technological R&D capabilities when strengthening environmental regulatory policies. For example, R&D subsidies, tax incentives, and other complementary measures can be provided to reduce the potential costs of technological innovation for enterprises.

### 6.2. Policy Implications

This study reveals the importance of the current environmental benefits and talent dividends. It provides policy insights for enterprises to realize innovative development and for local governments to promote high-quality economic development. For enterprises, it is necessary to improve the executive selection mechanism and top management structure, select executives who match the abilities required by enterprises, set up a reasonable compensation incentive system, and provide executives with a good working environment. This can help to alleviate the negative impacts of air pollution on the innovation of enterprises and, ultimately, realize the fulfillment of environmental responsibility. For the government, it is crucial to promote and regulate clean production according to the local industrial structure and ensure the implementation of the concept of low-carbon development. To attract and retain innovative talents, local governments can improve and advertise their local talent policy, improve talent introduction-related supporting services, and provide talent with excess non-monetary benefits besides monetary subsidies, thereby enhancing the local talent-gathering capacity and alleviating the negative impacts of air pollution. In addition, considering the capital crowding-out effect of air pollution, policies such as R&D subsidies and tax incentives can be granted to reduce the R&D costs of enterprises, to some extent.

### 6.3. Limitations and Future Directions

This study still has the following limitations. First, we measured top management quality considering only some of the executives' background characteristics that affect innovation performance, and individual characteristics such as executives' behaviors and preferences were not taken into account. Second, the unavailability of job mobility data, such as corporate executives' original workplaces and out-flow destinations, limits extensive research on the environment-improving motivations and practical outcomes of corporate executive mobility. Third, we did not subdivide the local talent policies when testing the moderating effect of local talent policies; for example, the preferential policies for different types and levels of talent and the regional differences in various types of talent policies. Failure to consider these policy differences may lead to overly broad conclusions.

Future research can incorporate individual characteristics such as executives' behavioral preferences, leadership styles, or environmental awareness to construct a more comprehensive evaluation system for top management quality. Subsequent research can utilize big data technology and combine the internal data of companies to collect information on the growth and learning environment (e.g., birth city, university city), workplace change (original work city, out-flow work city), and other factors. This can make up for the lack of relevant information in the publicly available data sources and allow for research from the perspective of the trajectory of the flow of human capital to be conducted. In addition, future studies can also shed light on air pollution and corporate innovations in a cross-country context; for instance, through exploring the impacts of air pollution on executives' cross-border migration among Asia, Europe, the United States, and other economies. Finally, future research could examine the match between various talent policies and specific talents in greater detail, leading to a more accurate understanding of how local talent policies can mitigate the negative impacts of air pollution on corporate innovation.

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## Appendix A

**Table A1.** Results of the correlation analysis.

| | **Patent~y** | **Patent~t** | **RD-Ratio** | **LnPM** | **TMTQ** | **Capital** | **Leverage** |
|---|---|---|---|---|---|---|---|
| PatentApply | 1 | | | | | | |
| PatentGrant | 0.823 *** | 1 | | | | | |
| RD-Ratio | 0.159 *** | 0.124 *** | 1 | | | | |
| LnPM | −0.139 *** | −0.109 *** | −0.035 *** | 1 | | | |
| TMTQ | 0.205 *** | 0.196 *** | 0.062 *** | −0.107 *** | 1 | | |
| Capital | −0.098 *** | −0.096 *** | −0.202 *** | −0.057 *** | 0.035 *** | 1 | |
| Leverage | 0.113 *** | 0.104 *** | −0.215 *** | 0.023 *** | 0.00500 | −0.129 *** | 1 |
| Liquidity | 0.065 *** | 0.077 *** | 0.240 *** | 0.0120 | 0.118 *** | −0.166 *** | −0.176 *** |
| TobinQ | −0.072 *** | −0.065 *** | 0.226 *** | −0.050 *** | −0.060 *** | 0.00800 | −0.258 *** |
| ROA | 0.053 *** | 0.030 *** | 0.180 *** | 0.00500 | 0.081 *** | −0.178 *** | −0.397 *** |
| lnSale | 0.409 *** | 0.376 *** | −0.114 *** | 0.033 *** | 0.146 *** | −0.384 *** | 0.500 *** |
| LnAge | 0.135 *** | 0.115 *** | −0.171 *** | 0.020 ** | −0.243 *** | 0.00900 | 0.404 *** |
| BoardIndSize | 0.050 *** | 0.055 *** | 0.0130 | −0.037 *** | −0.106 *** | 0.061 *** | −0.031 *** |
| FDI | −0.027 *** | −0.016 * | 0.038 *** | 0.227 *** | 0.082 *** | −0.027 *** | 0.023 *** |
| Structure | −0.139 *** | −0.113 *** | −0.107 *** | 0.128 *** | −0.077 *** | −0.155 *** | −0.0120 |
| GDP | 0.262 *** | 0.253 *** | 0.200 *** | 0.118 *** | 0.089 *** | 0.073 *** | −0.066 *** |
| GDPAvg | 0.278 *** | 0.274 *** | 0.202 *** | 0.041 *** | 0.038 *** | 0.056 *** | −0.090 *** |
| Suntime | −0.019 ** | −0.028 *** | −0.024 ** | 0.115 *** | 0.0180 | 0.085 *** | 0.072 *** |
| Temperature | 0.109 *** | 0.106 *** | 0.135 *** | −0.277 *** | 0.059 *** | −0.077 *** | −0.106 *** |
| | Liquid~y | TobinQ | ROA | lnSale | LnAge | BoardI~e | FDI |
| Liquidity | 1 | | | | | | |
| TobinQ | 0.078 *** | 1 | | | | | |
| ROA | 0.182 *** | 0.201 *** | 1 | | | | |
| lnSale | −0.149 *** | −0.305 *** | 0.030 *** | 1 | | | |
| LnAge | −0.336 *** | 0.036 *** | −0.239 *** | 0.426 *** | 1 | | |
| BoardIndSize | 0.029 *** | 0.032 *** | −0.024 *** | −0.017 ** | −0.022 ** | 1 | |
| FDI | 0.097 *** | −0.00400 | 0.0110 | −0.00100 | −0.00700 | −0.00900 | 1 |
| Structure | −0.024 *** | −0.022 ** | 0.034 *** | −0.113 *** | −0.101 *** | −0.079 *** | 0.033 *** |
| GDP | 0.144 *** | 0.051 *** | 0.032 *** | 0.088 *** | −0.028 *** | 0.098 *** | 0.140 *** |
| GDPAvg | 0.116 *** | 0.065 *** | 0.037 *** | 0.091 *** | −0.015 * | 0.101 *** | 0.094 *** |
| Suntime | −0.060 *** | −0.128 *** | −0.061 *** | 0.106 *** | 0.093 *** | 0.00200 | 0 |
| Temperature | 0.081 *** | 0.105 *** | 0.079 *** | −0.088 *** | −0.142 *** | 0.042 *** | 0.00200 |
| | Struct~e | GDP | GDPAvg | Suntime | Temper~e | | |
| Structure | 1 | | | | | | |
| GDP | −0.527 *** | 1 | | | | | |
| GDPAvg | −0.304 *** | 0.758 *** | 1 | | | | |
| Suntime | −0.324 *** | 0.107 *** | 0.067 *** | 1 | | | |
| Temperature | 0.185 *** | 0.099 *** | 0.186 *** | −0.641 *** | 1 | | |

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

## Appendix B

**Table A2.** Regression results for early patent term.

| | (1) | (2) | (3) |
|---|---|---|---|
| Panel A | | | |
| | $PatentApply_{t+1}$ | $PatentApply_{t+2}$ | $PatentApply_{t+3}$ |
| LnPM | −0.2992 *** | −0.2362 *** | −0.1902 *** |
| | (0.0470) | (0.0532) | (0.0577) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 10582 | 9145 | 7819 |
| $R^2$ | 0.3489 | 0.3055 | 0.2604 |
| Panel B | | | |
| | $PatentGrant_{t+1}$ | $PatentGrant_{t+2}$ | $PatentGrant_{t+3}$ |
| LnPM | −0.3666 *** | −0.3005 *** | −0.2188 *** |
| | (0.0489) | (0.0579) | (0.0617) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 10582 | 9145 | 7819 |
| $R^2$ | 0.336 | 0.298 | 0.239 |

Note: *t*-values in parenthesis, *** $p < 0.01$.

## Appendix C

**Table A3.** Regression results after adjusting for firm innovation indicators.

| | (1) | (2) |
|---|---|---|
| **Variable** | **IPatentApply** | **UnIPatentApply** |
| LnPM | −0.2671 *** | −0.3501 *** |
| | (0.0442) | (0.0456) |
| Controls | Yes | Yes |
| Year | Yes | Yes |
| Industry | Yes | Yes |
| N | 13,654 | 13,654 |
| $R^2$ | 0.361 | 0.29 |

Note: *t*-values in parentheses, *** $p < 0.01$.

## Appendix D

**Table A4.** Regression results of air pollution AQI and firm innovation.

| | (1) | (2) | (3) |
|---|---|---|---|
| | **PatentApply** | **PatentGrant** | **RD_Ratio** |
| LnAQI | −0.2357 *** | −0.1886 ** | −0.0025 *** |
| | (0.0670) | (0.0754) | (0.0009) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 12,504 | 12,504 | 10,075 |
| $R^2$ | 0.363 | 0.342 | 0.162 |

Note: *t*-values in parentheses, ** $p < 0.05$, *** $p < 0.01$.

## Appendix E

**Table A5.** Regression results after deleting the sample of cities in the north, Shanghai, Guangzhou, and Shenzhen.

| | (1) | (2) | (3) |
|---|---|---|---|
| | **PatentApply** | **PatentGrant** | **RD_Ratio** |
| LnPM | −0.3704 *** | −0.2380 *** | −0.0012 ** |
| | (0.0423) | (0.0477) | (0.0006) |
| Controls | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes |
| N | 11,242 | 11,242 | 8643 |
| $R^2$ | 0.40 | 0.378 | 0.156 |

Note: *t*-values in parentheses, ** $p < 0.05$, *** $p < 0.01$.

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