Stay or Leave? The Impact of Haze Pollution on Innovation Talent Mobility in China

ABSTRACT

This paper investigates how haze pollution —locally known as “wumai” in China— drives the migration of high-tech industry inventors in China and its subsequent impact on firms’ innovation. By analyzing an unbalanced panel dataset covering 128 cities, 1,460 firms, and 34,762 city-inventor-year observations from 2008 to 2019, the research highlights that deteriorating air quality compels inventors to relocate to cities with better environmental conditions, thereby reducing the innovation output of firms in polluted regions. Furthermore, this research identifies the moderating effects of regional economic disparities (GDP gap), differences in urban innovation ecosystems, firm state ownership, and inventors’ patent productivity on migration decisions. These findings underscore the role of environmental factors in talent mobility and provide actionable insights for policymakers seeking to retain skilled professionals in pollution-affected areas.

Keywords:

Haze pollution; talents migration; GDP gap; urban innovation vitality gap; state ownership; inventors’ patent output

Introduction

The migration of talent, particularly within the high-tech industry, is a critical determinant in shaping the landscape of global innovation and economic development (Kerr et al., 2016; Shi & Lai, 2019; Mao, Latukha, & Selivanovskikh, 2022). High-tech industry inventors, as key drivers of technological advancement, play a crucial role in fostering economic growth (Atun, Harvey, & Wild, 2007), enhancing national competitiveness (Athreye & Cantwell, 2007; Wu, Ma, & Zhuo, 2017), and propelling societal progress (Zeng, 2006). The geographic mobility of these inventors is not merely a reflection of personal or professional choices; it is also indicative of broader socio-economic and environmental trends that shape where innovation thrives (Moretti, 2021). Traditional wisdom in economics and management has long emphasized salary, career advancement, and agglomeration effects as primary drivers in the migration decisions of skilled labor (XXXXXX). However, environmental factors—particularly air pollution—have increasingly emerged as a critical determinant of talent flow, fundamentally challenging the adequacy of conventional models that treat migration as a function of economic returns alone.

From the perspective of human capital theory, inventors are highly sensitive to health and productivity risks that may compromise cognitive performance (XXXXXXXXX), while migration choice theory emphasizes that such risks act as powerful “push factors,” reshaping the cost–benefit calculus of relocation (XXXXXXXXX). These insights provide a foundation for understanding how environmental conditions influence talent mobility. However, the precise mechanisms through which persistent environmental stressors—especially those that are visibly salient and directly threaten health—alter the migration decisions of high-value innovators remain inadequately explored. In particular, there is limited understanding of how acute, large-scale environmental crises translate into tangible mobility patterns among inventors (XXXXXXXXX), whose work depends critically on sustained cognitive capacity and long-term well-being.

China offers a particularly salient context to investigate this phenomenon. Since 2013, severe haze pollution—locally known as wumai—has become a visible and persistent environmental hazard, generating widespread public concern and prompting extensive policy responses (Jia et al., 2021). Unlike other types of pollution—such as water, soil, or solid waste—that are often less visible and perceived as more distant from daily life, haze pollution possesses several distinctive features: it is highly frequent, geographically widespread, directly perceptible, and closely tied to respiratory and cognitive health risks. In particular, haze pollution in China is characterized by extremely high concentrations of PM2.5—often exceeding 100 $\mu g/m^3$ during winter months—caused by coal combustion for heating, vehicular emissions, industrial discharge, and agricultural residue burning, compounded by atmospheric stagnation in the North China Plain where meteorological and topographical conditions trap pollutants (Zhang et al., 2017). As a result, haze pollution generates an immediate and unavoidable impact on individuals' daily lives, creating a form of environmental stress that is not only more visible but also more psychologically salient than other environmental hazards. Recognizing the urgency of the problem, the Chinese government launched the "Blue Sky Defense War" in 2013, initiating a comprehensive series of environmental reforms aimed at improving air quality. These measures included phasing out small coal-fired boilers, transitioning to cleaner energy sources, upgrading industrial emissions standards, and building an extensive air quality monitoring network. By 2023, these efforts had led to a nationwide reduction of approximately 34% in annual average PM2.5 levels. Yet, despite such notable progress, haze pollution remains a persistent challenge. In February 2025, Chinese authorities once again reaffirmed their commitment to eliminating all instances of severe air pollution by the end of the year, underscoring both the centrality of clean air to national development and the ongoing difficulties of sustaining environmental improvements.

Within this context, haze pollution is not only an environmental and public health concern but also an increasingly salient factor shaping the dynamics of innovation talent. Prolonged exposure to high concentrations of PM2.5 has been shown to impair respiratory function, reduce cognitive performance, and negatively affect overall well-being (Kelly & Fussell, 2015). For high-tech inventors—whose work is highly cognitive, creativity-driven, and health-dependent—such adverse effects are particularly consequential, directly lowering productivity and heightening the incentive to relocate to cleaner and more livable urban environments (Ai et al., 2022; Liao et al., 2022). From the perspective of human capital theory, the potential erosion of inventors' productivity due to haze acts as a critical "push factor" in migration decisions. Consistent with migration choice theory, the costs of remaining in polluted regions increasingly outweigh potential economic or professional benefits. Moreover, from the lens of environmental constraint theory and regional innovation systems theory, the pervasive and perceptible nature of haze imposes unique constraints on the spatial distribution of innovation talent, making air quality a structural determinant of regional innovation capacity.

Within this context, this study develops a comprehensive analytical framework that examines how haze pollution influences inventors' migration decisions through the interplay of economic conditions, innovation ecosystems, individual career development, and firm-level institutional factors. While air pollution may trigger the migration of high-tech inventors, their decision to migrate is rarely driven by a single factor; economic and innovation-related considerations also play an important role (Lissoni, 2018; Wang, 2022). Economic disparities between regions, reflected in differences in GDP, can influence the attractiveness of a destination city (Neves, Fernandes, & Pereira, 2015; Romão et al., 2018). Cities with stronger economies typically offer better job opportunities, higher salaries, and more robust infrastructure, making them appealing destinations for high-tech talent (Buch et al., 2017; Thisse, 2018). Similarly, the vitality of a city's innovation ecosystem—its capacity to support research, development, and technological advancement—can significantly affect the migration patterns of inventors (Appio et al., 2019; Jin, Mangla, & Song, 2022). Cities with vibrant innovation ecosystems provide better support for high-tech professionals, offering them the resources, networks, and collaborative opportunities necessary for their work (Jin et al., 2022). Thus, our research examines the moderating effects of the GDP gap and the disparity in innovation vitality between origin and destination cities on the relationship between haze pollution and inventors' migration decisions..

In addition to economic and innovation-related factors, high-tech inventors' migration decisions are strongly influenced by their career development, as job security, access to resources, and professional growth opportunities within their current firms may outweigh the benefits of relocating (Carr, Inkson, & Thorn, 2005; Choudhury, 2022; Lee & Clarke, 2019; Wang, 2022), even in the face of environmental challenges like haze pollution. State ownership of a firm provides job security and long-term benefits (Kurtulus & Kruse, 2017; Wong, 2018), making inventors less likely to migrate despite environmental challenges. Meanwhile, an inventor's patent output reflects their market value and career mobility (Crespi, Geuna, & Nesta, 2007; Melero, Palomeras, & Wehrheim, 2020; van der Wouden & Rigby, 2021), potentially encouraging relocation to cities with better opportunities and living conditions. These two factors—state ownership and innovation output—are key in shaping inventors' migration decisions. Therefore, our research examines the moderating effects of state ownership and inventors' patent output on the relationship between haze pollution and their migration decisions.

We test our conceptual framework using a sample that includes 128 cities, 1,460 firms, and 34,762 city-firm-inventor-year observations from 2008 to 2019, making three key contributions to the literature. First, our study contributes to the existing literature by examining the environmental externalities of brain drain on economic growth. While most studies examine firm-level determinants of innovation (Balsmeier, Fleming, & Manso, 2017; Custódio, Ferreira, & Matos, 2019; Manso, 2011), our research delves into the micro-level dynamics of inventor mobility. Specifically, inventors tend to migrate from polluted areas, which, in turn, negatively affects firms' innovation output. In this paper, we quantify the sensitivity of inventor migration to air pollution and the economic consequences of brain drain on firm innovation. Second, to supplement the literature on human capital migration due to air pollution (Chen, Guo, & Huang, 2018; Levine et al., 2020; Xue et al., 2021), we focus primarily on the migration of inventors, a specific type of highly skilled laborer. Given the importance of inventors to economic growth, our findings also add to the literature on the driving factors of inventor mobility (Akcigit, Baslandze, & Stantcheva, 2016; Chemmanur et al., 2019; Cheyre, Klepper, & Veloso, 2015; Hombert & Matray, 2017; Palomeras and Melero, 2010). Third, we consider the GDP gap and urban innovation vitality disparity between origin and destination cities as indicators of economic and innovation attractiveness, alongside state ownership and inventors' patent output as career-related factors, which adds nuance to the analysis compared to studies that treat pollution as a uniform variable (Chang, Huang, & Wang, 2018; Dong et al., 2021). This perspective provides a more complex and realistic analysis.

Theoretical Framework and Hypotheses

Theory in Talent Migration

Existing studies on the relationship between environmental quality and skilled - labor mobility have drawn upon diverse theoretical lenses. At the individual level, classical push – pull models (Lee, 1966; de Haas, 2010) and neoclassical migration theory (Todaro, 1969) conceptualize environmental degradation as a push factor and urban amenities as a pull factor. The aspirations–capabilities framework (Carling, 2002) extends this logic by highlighting how perceived opportunities and constraints jointly determine whether migration intentions translate into actual mobility. Human capital theory (Becker, 1964) interprets relocation as a utility-maximizing reallocation, in which skilled workers weigh productivity-enhancing opportunities against health or cognitive costs induced by poor air quality (Graff Zivin & Neidell, 2014).

At the regional level, New Economic Geography emphasizes the role of agglomeration economies, spatial frictions, and locational amenities in shaping mobility decisions (Krugman, 1991; Glaeser & Gottlieb, 2009). Pollution can be theorized as a spatial friction that raises the costs of staying in a location and reduces the attractiveness of urban clusters. From a macro perspective, world-systems theory (Massey et al., 1999; Sager, 2012) also suggests that core regions—characterized by advanced economies, stronger institutions, and superior environmental conditions—are more likely to attract high-skill talent from peripheral regions.

At the organizational and institutional level, ecological modernization theory argues that environmental regulation can stimulate technological upgrading and improve living conditions, thereby supporting talent retention (Mol & Sonnenfeld, 2000). The natural resource–based view extends this idea by conceptualizing environmental quality and urban amenities as strategic assets in the competition for skilled labor (Hart, 1995; Delmas & Pekovic, 2013). Institutional theory further highlights how regulatory regimes and ownership structures shape both corporate environmental performance and labor mobility outcomes (DiMaggio & Powell, 1983; Peng, Sun, Pinkham, & Chen, 2009). For instance, state ownership may dampen the sensitivity of mobility decisions by offering stronger employment security but weaker responsiveness to environmental risks (Li & Qian, 2013).

Despite these insights, prior applications have been fragmented rather than integrative. Most scholarship treats pollution as a homogeneous externality, overlooking its heterogeneous impact across occupational groups. Critically, it has paid limited attention to the migration of innovative talents such as R&D inventors—a pivotal cohort in knowledge economies (Breschi, Lissoni, & Temgoua, 2016). These inventors depend on sustained cognitive functioning that is vulnerable to air pollution (Chang, Graff Zivin, Gross, & Neidell, 2019); they are embedded in epistemic communities requiring a critical mass of peers (Cerna & Chou, 2019); and they serve as central nodes in both firm-level knowledge networks and regional innovation ecosystems (Fleming, King, & Juda, 2007). As such, their locational choices extend beyond basic living conditions to encompass the viability of the surrounding intellectual ecosystem—including access to research infrastructure, density of peer communities, and long-term funding opportunities.

To capture these dynamics, this study advances an integrated multi-level theoretical framework that synthesizes insights from migration theory, spatial economics, human capital theory, and strategic management. At the individual level, push–pull and aspirations–capabilities perspectives explain how worsening haze pollution increases health risks and cognitive costs that push inventors away, while economically vibrant and innovative cities exert pull forces. At the regional level, New Economic Geography situates pollution as a spatial friction interacting with agglomeration economies, thereby influencing inventors' relocation calculus. At the organizational and institutional level, ecological modernization, the natural resource–based view, and institutional theory highlight how environmental quality, corporate governance (especially state ownership), and regulatory regimes moderate both the perceived security of staying and the incentive to move.

This integrated framework provides a multi-level explanation of inventors' migration under haze pollution. It not only addresses the fragmentation of existing perspectives but also theorizes the unique vulnerabilities and strategic value contributions of innovative talents. In doing so, it extends the literature on talent mobility by situating inventors' migration decisions at the intersection of individual rationality, regional spatial dynamics, and institutional-structural constraints.

Haze Pollution and Talent Flow Choice

We propose that haze pollution increases the likelihood that high-tech industry inventors migrate to cities with better air quality. This hypothesis is grounded in a multi-level theoretical framework that integrates individual characteristics, cognitive and health considerations, and environmental values, while accounting for policy context. First, high-tech industry inventors possess unique characteristics that render them more mobile compared to other workers (Hoisl, 2007; Palomeras & Melero, 2010). Their specialized knowledge and technical expertise afford them unique opportunities to negotiate relocation packages or seek employment in cities with better air quality (Murray, 2004). Many of these inventors work in high-paying sectors, enabling them to absorb migration costs, such as moving expenses and securing housing in more expensive urban areas (Haller, 2022). Their relatively high-income levels and bargaining power mean that air pollution may serve as a significant enough motivator to prompt migration, without the financial concerns that might limit workers in other industries (Liu et al., 2023). This high mobility enhances their ability to respond to external environmental factors, such as haze pollution. Consequently, high-tech inventors are more likely to migrate to cities with better air quality when faced with deteriorating environmental conditions due to their superior migration capabilities.

Second, high-tech inventors often work in cognitively demanding environments where creativity, focus, and problem-solving skills are essential (Park, 2005; Wang et al., 2024). Exposure to haze pollution is associated with various health issues, including respiratory and cardiovascular diseases, as well as cognitive impairments such as reduced memory, attention, and decision-making abilities (Chandra et al., 2022; Qiu, Yang, & Lai, 2019). These adverse effects on health and innovation output make it more likely that high-tech industry inventors, who rely heavily on their intellectual capacity, would choose to migrate to cities with better air quality to maintain their productivity and well-being.

Third, with increasing global concerns about climate change and environmental degradation, high-tech industry inventors are becoming more environmentally conscious (Mousavi, Bossink, & van Vliet, 2019). Many inventors work in industries that prioritize sustainability, such as clean energy, electric vehicles, or green technology, making them more inclined to seek out cities with environmentally friendly policies and lower levels of pollution (Marra, Antonelli, & Pozzi, 2017). Haze pollution, in particular, can conflict with their personal values and professional interests, prompting them to relocate to cities that align with their environmental values.

H1: Haze pollution increases the likelihood that high-tech industry inventors migrate to cities with better air quality.

Urban attraction, haze pollution and inventors' flow choice

The decision of high-tech industry inventors to migrate in response to haze pollution is influenced not only by environmental factors but also by the career-related opportunities offered by potential destinations. From the perspective of career concern theory, inventors weigh the trade-off between environmental risks and career development prospects, such as access to resources, professional networks, and long-term advancement opportunities (Holmström, 1982; Prendergast, 1999). In this context, urban attractiveness, reflected in economic and innovation disparities between departure and destination cities, serves as a key determinant of migration choices.

Specifically, cities with higher GDP provide superior infrastructure, living standards, and employment opportunities, which align with inventors' goals of career stability and growth. Cities with stronger innovation vitality offer richer knowledge networks, R&D resources, and professional development prospects, directly supporting inventors' ability to accumulate career capital and enhance their professional reputation (Baker, Khater, & Haddad, 2019; Dvir & Pasher, 2004; Gao et al., 2023). Therefore, high-tech inventors evaluate potential destinations not only based on environmental quality but also according to the career-enhancing benefits these cities can offer. The interaction between urban attractiveness and environmental conditions reflects the career-oriented trade-offs inventors make, providing a theoretically grounded explanation for heterogeneous migration responses to haze pollution.

The decision of high-tech industry inventors to migrate in response to haze pollution is not solely influenced by environmental factors. Economic disparities between the departure and destination locations play a critical role in shaping the intensity and direction of this migration (Czaika, 2015). Specifically, GDP, as a measure of economic activity and prosperity, reflects the availability of resources, infrastructure, and opportunities in a region (Baker, Khater, & Haddad, 2019). Cities with higher GDPs typically offer better job prospects, higher salaries, more advanced infrastructure, and a more vibrant business environment. For high-tech industry inventors, these economic factors are highly attractive, as they seek not only cleaner air but also environments that support their professional growth and innovation activities.

We propose that the greater the GDP gap between the destination and departure locations, the more pronounced the effect of haze pollution on high-tech industry inventors' migration to cities with better air quality. First, larger GDP gaps between departure and destination cities reflect significant differences in living standards, infrastructure, and services, including access to healthcare, education, and urban amenities (Gao et al., 2023). Cities with higher GDPs generally offer a better quality of life, which is crucial for high-tech inventors. In polluted cities, the adverse effects of haze on health and well-being may drive inventors to prioritize cities with better public services and cleaner environments. The greater the disparity in GDP between cities, the more attractive the destination city becomes, as it likely offers not only cleaner air but also superior healthcare, housing, and overall quality of life, making relocation more appealing.

Second, cities with higher GDPs often have more robust and dynamic economies, which tend to provide better employment opportunities, particularly for highly skilled workers like high-tech inventors. High-GDP cities typically house larger corporations, innovation hubs, and cutting-edge research institutions (Steinbock, 2008). The availability of enhanced career advancement opportunities and professional development in these cities creates a strong pull for inventors considering migration. When haze pollution worsens living and working conditions in lower-GDP cities, the potential for greater economic rewards and career growth in high-GDP cities amplifies the migration effect. Thus, the GDP gap heightens the appeal of relocating to cities with superior economic prospects and cleaner environments.

Third, high-GDP cities are often centers of technological innovation, offering inventors access to superior research facilities, financial resources, and collaborative opportunities (Gao et al., 2023). The innovation ecosystem in such cities thrives due to the presence of venture capital, government support, and multinational corporations (Ning, Xu, & Long, 2019). For high-tech inventors experiencing the health and productivity risks associated with haze pollution, relocating to a higher-GDP city can provide access to an ecosystem that not only supports their professional growth but also offers a cleaner, healthier environment. The greater the gap in innovation resources between the departure and destination cities, the stronger the motivation to migrate. As a result, the combination of better air quality and superior innovation infrastructure drives inventors toward higher-GDP cities. We thus propose the following hypothesis:

H2: The larger the GDP gap between destination and departure cities, the more likely high-tech industry inventors are to migrate to cities with better air quality in response to haze pollution.

We propose that the larger the gap in urban innovation vitality between the destination and departure locations, the more pronounced the effect of haze pollution on high-tech industry inventors' migration to cities with better air quality. First, urban innovation vitality refers to a city's capacity to foster technological advancement, entrepreneurship, and knowledge generation (Dvir & Pasher, 2004). Cities with higher innovation vitality typically host well-established technology hubs, research institutions, and a dynamic network of startups, offering high-tech inventors an environment that nurtures creativity and development (Esmaeilpoorarabi, Yigitcanlar, & Guaralda, 2018). Faced with haze pollution, high-tech inventors may be drawn to cities with stronger innovation vitality, which not only offer better air quality but also provide access to cutting-edge resources, collaborations, and funding. The larger the gap in innovation vitality between the origin and destination cities, the stronger the incentive for inventors to relocate to cleaner cities with more vibrant innovation ecosystems that support their professional growth.

Second, cities with high innovation vitality create networks that facilitate knowledge exchange, cross-industry collaboration, and innovation spillovers (Breschi & Lissoni, 2009; Hoisl, 2007). These networks enhance inventors' ability to work on pioneering projects and stay at the forefront of technological development (Roberts, 2007). In contrast, cities with low innovation vitality may lack such collaborative networks and opportunities for growth. When haze pollution exacerbates the challenges of living and working in less innovative cities, high-tech inventors are more likely to migrate to cities where innovation is thriving and air quality is better. The larger the disparity in the innovation climate, the more pronounced the effect of haze pollution on their migration decisions, as these inventors seek environments conducive to both personal well-being and professional advancement.

Third, high-tech inventors are particularly sensitive to factors that influence their long-term career trajectory, including the availability of R&D investments, cutting-edge infrastructure, and government support for innovation (Carr et al., 2005). Cities with higher innovation vitality are often better equipped to offer sustained opportunities for inventors to advance their careers and make significant contributions to their fields (Dvir & Pasher, 2004). If haze pollution degrades the quality of life in lower-innovation cities, the combined pull of cleaner air and enhanced career prospects in high-innovation cities becomes a strong driver of migration. The larger the gap in innovation vitality between the cities, the more pronounced the migration effect, as inventors are drawn to locations where they can maximize both their professional potential and their personal health and well-being. We thus propose that:

H3: The larger the gap in urban innovation vitality between destination and departure cities, the more likely high-tech industry inventors are to migrate to cities with better air quality in response to haze pollution.

Career concern, haze pollution and inventors' flow choice

The impact of haze pollution on the migration decisions of high-tech industry inventors is not uniform; it depends on factors that reflect inventors' career concerns, defined as the degree to which individuals prioritize long-term career development, job security, and professional reputation when making decisions (Holmström, 1982; Prendergast, 1999). Within this framework, inventors' migration choices are influenced not only by environmental quality but also by the trade-offs between career stability and environmental risks. In this study, we focus on two key moderators: state ownership of the firm and inventors' innovation output capability, because these variables directly capture different dimensions of career concern.

State ownership represents institutional and organizational career security: SOEs provide long-term employment stability, government-backed resources, and structured career paths that reduce the incentive to relocate, even under adverse environmental conditions. Innovation output capability captures personal career capital: inventors with higher innovation output are more embedded in local innovation networks, possess greater bargaining power, and can influence workplace conditions to mitigate environmental risks without leaving. By integrating these two moderators into our framework, we can test how both institutional career concerns (state ownership) and individual career capital (innovation output) shape responses to haze pollution, offering a theoretically grounded explanation for the heterogeneity in migration behavior.

We propose that the impact of haze pollution on the migration decisions of high-tech industry inventors can be influenced by various factors, including the level of state ownership in their firms. We propose that a higher level of state ownership in an inventor's firm will weaken the effect of haze pollution on their decision to migrate to cities with better air quality. First, state-owned enterprises (SOEs) are often perceived as providing greater job security, stability, and long-term employment benefits compared to private firms (Moore & Jie, 2006; Wong, 2018). Inventors employed by SOEs may be less inclined to migrate, even in the face of haze pollution, as they prioritize the stability and benefits associated with their employment, such as guaranteed pensions, comprehensive medical coverage, and opportunities for career growth within the state structure. The security offered by SOEs can offset the negative effects of haze pollution, reducing the incentive to relocate for better air quality. Therefore, the higher the level of state ownership in a firm, the less likely it is that an inventor will prioritize environmental concerns over job stability, thereby weakening the migration effect.

Second, SOEs often have access to government-supported resources, such as subsidized housing, healthcare, and transportation, which can mitigate the adverse effects of pollution on employees' lives (Wang et al., 2022; Yu et al., 2021). In heavily polluted cities, SOEs may offer additional perks to retain key talent, such as air purification systems in offices, financial incentives, or even relocation packages within the same city. These government-backed advantages create a buffer against the detrimental impact of haze pollution, reducing the urgency for inventors to seek out cities with better air quality. As state ownership increases, the significance of government-provided resources grows, further weakening the need for migration in response to environmental degradation.

Third, high-tech inventors working for SOEs may have stronger political and organizational ties that limit their mobility. State ownership often comes with implicit expectations of loyalty, career progression within the organization (Ralston et al., 2006), and reduced flexibility in relocating to other regions or firms. Additionally, inventors in SOEs may be involved in projects of national significance (Huang et al., 2021), which could bind them to their current location despite environmental challenges. This institutional attachment diminishes the likelihood of migration, as haze pollution is viewed as an obstacle that can be managed rather than a compelling reason for relocation. As the level of state ownership increases, these ties strengthen, further weakening the effect of pollution on migration behavior. We thus propose that:

H4: A higher level of state ownership in the inventor's firm decreases the likelihood that high-tech industry inventors migrate to cities with better air quality in response to haze pollution.

Innovation output capability refers to an inventor's ability to generate successful and impactful innovations, typically measured by the number of patents filed, successful product launches, or other indicators of technological advancement (Chandy et al., 2006; Janger et al., 2017). Inventors with high innovation output capabilities are often highly regarded in their fields due to their proven track record of significant contributions to technology and innovation (Murray, 2004). These individuals possess several advantages that influence their response to haze pollution. First, high-tech inventors with greater innovation output capability are valuable assets to their firms (Arora et al., 2023; Bhaskarabhatla et al., 2021). Their strong bargaining power allows them to negotiate better working conditions and incentives, such as higher salaries, bonuses, or even relocation packages within the same polluted city (Scotchmer, 1991; Spulber, 2016). To retain such valuable talent, firms are more likely to invest in resources like air purification systems, enhanced healthcare benefits, or flexible working arrangements. As a result, these inventors may be less inclined to migrate solely due to haze pollution, as their firms provide solutions that mitigate its negative impact, thus weakening the migration effect.

Second, inventors with higher innovation output capabilities are often deeply embedded in local innovation ecosystems, with well-established networks of collaborators, clients, and ongoing projects (Granstrand & Holgersson, 2020). Relocating to another city could disrupt these valuable connections, resulting in a potential loss of momentum in their current work. Moreover, such inventors are likely to have already invested significantly in local infrastructure and resources that support their high productivity (Furman, Porter, & Stern, 2002). The opportunity costs of leaving these well-established networks outweigh the potential benefits of moving to a city with better air quality, making them less likely to migrate, despite the presence of haze pollution.

Third, due to their substantial contributions and influence within their firms, high-output inventors may have a greater capacity to advocate for workplace changes that improve environmental conditions. They can push for firm-level environmental improvements or corporate social responsibility (CSR) initiatives aimed at reducing the impact of haze pollution on employees. This enhanced ability to influence their work environment reduces the pressure to relocate for better air quality. The higher an inventor's innovation output capability, the more control they have over their working conditions, which in turn diminishes the likelihood of migration. We thus propose that:

H5: Inventors with higher innovation output capability are less likely to migrate to cities with better air quality in response to haze pollution.

Research Methodology

Data Source

Our sample covers high-tech manufacturing firms listed on the Shanghai and Shenzhen Stock Exchanges from 2000 to 2019 in China. The manufacturing firms in high-tech industries in China provide a rich setting for our research. First, high-tech manufacturing firms in China, especially those listed on the Shanghai and Shenzhen Stock Exchanges, are clustered in major urban centers known for their innovation capacity. These cities are home to highly skilled inventors who drive technological advancement. As these areas also experience significant pollution, this sample is ideal for studying how environmental factors, such as haze pollution, influence the migration decisions of these key inventors. Second, the 2008 to 2019 timeframe encompasses periods of both rising haze pollution and increased regulatory efforts to improve air quality in China. By analyzing firms over one decade, the research can examine how changes in air quality impact inventor migration over time, providing a nuanced understanding of how persistent or improving pollution levels influence mobility decisions. Third, high-tech industries in China are heavily reliant on human capital and innovation output, making inventor mobility a critical factor in firm competitiveness. Pollution-related health risks and declining living conditions can diminish the productivity and well-being of inventors, pushing them to migrate. The availability of firm-level data on innovation outputs, combined with environmental data, allows for a detailed analysis of the relationship between air quality and inventor migration.

We first identified all A-share firms listed on the Shanghai and Shenzhen Stock Exchanges from the China Stock Market & Accounting Research (CSMAR) database. CSMAR is a comprehensive research-oriented database focusing on China Finance and Economy. We used the Industry Code (2012) of the China Securities Regulatory Commission (CSRC) and “High-Tech Industry (Manufacturing) Classification 2017” issued by China’s National Bureau of Statistics to identify high-tech industries that use advanced science and technology in the development of inventions, such as drugs, chemicals, and electronics (Liu & Buck, 2007; Qian & Li, 2003). Chinese high-tech manufacturing industries are divided into 21 subsectors according to the industrial classification system used by China’s National Bureau of Statistics and we chose CSRC industry codes by comparing these 21 subsectors. According to this standard, our final selection of high-tech industries includes Chemical Manufacturing (C26), Medical and Pharmaceutical Products (C27), Aircraft and Spacecraft (C36 and C37), Electronic and Telecommunications Equipment (C33, C34, C35, and C38), Computer and Office Equipment (C39), and Medical Equipment and Meters (C40).

We relied on several sources to compile our data. First, we collected patent data from China’s State Intellectual Property Office (SIPO), which includes information such as the application date, application number, inventor, application address, applicant, patent classification number (IPC), and the number of citations. This provides a comprehensive population of all patent applications. Second, we identified patent data specific to the sample firms, including patent names, application dates, patent addresses, patent types, and IPC classification codes, all sourced from SIPO Patent Search and Service System database. Third, we gathered basic firm information, such as ownership structure and firm size, along with financial data on firms’ performance and valuation, from the WIND financial database and the China Stock Market & Accounting Research (CSMAR) database. Fourth, we obtained information on the cities where the firms are located, including patent application information and GDP data, from the China Research Data Service (CNRDS) platform. Fifth, we conducted data cleaning and preprocessing. Duplicate patent information retrieved from SIPO was removed to ensure the uniqueness of inventors. Firms with zero patent submissions during the observation period, or those classified as ST, *ST, PT, or with severely incomplete data were excluded. Lastly, we identified and eliminated duplicate inventor records based on patent application addresses and classification codes. Specifically, if a patent inventor applied for patents in different cities within the same year and the patents did not belong to the same major patent category, these cases were considered duplicates and removed. We ultimately compiled an unbalanced panel dataset featuring 128 cities, 1460 firms, and 34762 city-firm-inventors-year observations in the period from 2008 to 2019.

Variables

Inventor mobility. Using the information about the inventors and their employers, we track the career paths of the inventors. Following Marx, Strumsky, and Fleming (2009), we identify an inventor as a flowing inventor if he files two successive patent applications for different firms. Note that we augment the sample by filling the gap years between two application filings by each inventor. Following Hombert and Matray (2017), we assign the midpoint between the year in which the first patent is filed and the year in which the subsequent patent is filed as the moving year, and construct three variables to examine inventor mobility. The first variable is an indicator variable (denoted as *Flow*), which equals one if the inventor moves to a new city, and zero otherwise. The second variable is used to measure whether inventors moved to a city with better air quality (denoted as *Flow_up*). Specifically, we calculate the difference between the haze index of the departure and destination, and assign one if it is greater than zero, otherwise zero. We construct a third variable to measure whether inventors moved to a city with bad air quality (denoted as *Flow_down*). Specifically, we calculate the difference between the haze index of the departure and destination, and assign one f it is less than zero, otherwise zero. Considering the concurrent possibilities of inventors moving out and moving in, we construct a fourth variable of inventor mobility aggregated at the firm-year level (*Flow_firm*). *Flow_firm* is defined as the net outflow of inventors scaled by the total number of inventors in the firm at the beginning of the year.

Haze pollution. Because $PM_{2.5}$ is the main component of haze, we use $PM_{2.5}$ to characterize haze pollution. This article uses network grid data obtained by the satellite equipment of the Battle Institute and the Columbia University Socioeconomic Data and Application Center. In this paper, we use ArcGIS 10.0 to analyze grid data from 2008 to 2019 and obtain the $PM_{2.5}$ concentrations in 287 cities in China. At present, China's official $PM_{2.5}$ data come from ground monitoring stations, but China's vast territory and the distribution of monitoring stations are not intensive, so point-to-point ground monitoring cannot truly reflect China's haze pollution. The satellite equipment obtains surface-source data that can comprehensively capture the characteristics of $PM_{2.5}$ concentrations, making the data more authentic and accurate (Ye, Ma, & Ha, 2018).

GDP growth gap. GDP growth was measured as the percentage difference between the GDPs per capita in the current year and the GDP per capita in the previous year, relative to the GDP per capita in the previous year (Marattin & Salotti, 2011). We thus measured *GDP growth gap* as the difference of *GDP growth* between destination and departure.

Urban patent capability gap. Patent output is generally used as a comparative index of regional innovation capability (Chen, 2014). We thus measured *urban patent capability gap* as the difference between the number of patent applications in destination and departure as a measure of *urban patent capability gap.*

State ownership. We measure state ownership as the proportion of firms' total shares owned by the government, following Li et al. (2012) and Zhou et al. (2017).

Innovation ability of inventor. According to Toivanen and Väänänen (2012), we use citation patent counts as the indicator of innovation ability of inventor.

Control variables. Factors related to city, industry, firm and individual inventors are selected as controls in the empirical analyses. First, the indicators of technological innovation and talent in prefecture-level cities can reflect the city's technological innovation environment and talent development levels. A comprehensive reflection of a city's technological innovation and talent development levels directly influences talent migration decisions. Therefore, we control for *urban talent attention gap* and *urban innovation index gap* as corresponding indicators. Specifically, by compiling reports from listed firms and conducting word frequency statistics on aspects such as urban technological innovation and talent, we can monitor the *urban talent attention*[1]. Finally, we use the frequency of related keywords divided by the total annual word frequency of the prefecture-level city as the indicator of *urban talent attention*. We then calculate the difference of *urban talent attention* between departure and destination as the measure of *urban talent attention gap.* We also control for *urban innovation index gap* as the indicator of city's technological innovation environment. The value of China's Regional Innovation Capability Index is derived from *China's Regional Innovation Capability Report*[2]. We calculate the difference of China's Regional Innovation Capability Index between departure and destination as the measure of *urban innovation index gap.* In addition, we controlled for *urban GDP growth,* which was measured as the percentage difference between the GDP per capita in the current year and the

[1] Keywords include: scientific research, applied basic research, core technology, basic science, frontier technology, original innovation, key technology, public welfare technology, originality, technological talent: talent resources, high-level overseas talent, returnees, talent team building, reform of the scientific and technological system, the strategy of strengthening the nation through talent, the strategy of rejuvenating the nation through science and education, technological achievements, intellectual property, technological innovation, high-level talent, leading talent, innovation teams, talent teams, innovation and entrepreneurship, scientific research personnel, mass entrepreneurship and innovation, innovation-driven, etc.

[2] As one of the important reports of the national innovation survey system, The *China's Regional Innovation Capacity Evaluation Report* has evaluated and analyzed the innovation capacities of 31 regions (provinces, autonomous regions, and municipalities directly under the Central Government) for 20 consecutive years with the focus on the core topic of the construction of China's regional innovation system. The research data of the report are obtained from public material such as statistical yearbooks and government reports. According to the practice of relevant evaluation reports, the report uses data from two years ago and the missing data undergo smoothing. In November 2020, The China's Regional Innovation Capacity Evaluation Report of 2020 (hereinafter referred to as *Evaluation Report 2020*) was issued in Beijing. It systematically evaluates and analyzes the innovation capacities of 31 regions (provinces, autonomous regions, and municipalities directly under the Central Government) in China with the basic data in 2018.

GDP per capita in the previous year, relative to the GDP per capita in the previous year (Marattin & Salotti, 2011).

Second, we controlled for *industry competition* as it may affect inventors' decisions to move from firm to firm (Liu, Kong, & Zhang, 2024). We controlled HHI as the indicator of *industry competition.*

Third, we control for *firm size*, *firm age* and *firms' critical innovation* to account for the effects of firm characteristics and innovation features. We control for *firm size* by using the natural logarithm of total sales (Shalit & Sankar, 1977). Since older and larger firms often have more experience of environmental innovation activities (Tang et al., 2018b), we control for *firm age*, defined as a firm's age since its inception (Huang & Li, 2017). Furthermore, we control for *critical innovation* as the indicator of firms' innovation ability. The sum of patents in any IPC class for which a firm has not filed a patent in the five years prior to the year under observation is used to measure a *firm's critical innovation* (Ahuja & Katila, 2001; Phelps, 2010). For this purpose, we collect patent data from the SIPO website, identifying all of a firm's patents between year t–4 and year t, to calculate a firm's critical innovation at year t. Then, we use the first three digits of the IPC number for all patents of the firm for this period to check whether the patents have been in place in the preceding five years, including the current year. If so, we classify this patent as a critical patent. Last, we use the logarithm of the number of critical patents as the measurement of a firm's critical innovation.

Fourth, we control for individual inventors' features since individual innovation performance will influence inventors' mobility (Di Lorenzo & Almeida, 2017). We controlled for the *number of inventors' patents,* measured as the total number of patents application to each inventor each year. *Number of inventors' patent citations* was measured by the number of other patents cited by the inventor during the year. *Number of inventor teams measured as* the number of co-inventors in the inventor's set of patents in each year.

Empirical Tests

Haze Pollution and Inventors' Flow Choice

Given the binary nature of the dependent variable, logistic regression (xtlogit in Stata) was used to reveal the relationship between haze pollution and inventor flow choice in China (Wooldridge, 2013). Table 1 presents the descriptive statistics of and Pearson correlation between the main variables of the study. Table 2 depicts the logistic regression results of the influence of haze pollution on inventors' flow choice (*flow*), flow to a city with better air quality (*flow_up*) and flow to a city with bad air quality (*flow_down*). Model 1, Model 3 and Model 5 only includes control variables. Model 2, Model 4 and Model 6 test the effect of haze pollution on *flow, flow_up and flow_down,* respectively. The results of Models 2 in Table 2 show the effect of haze pollution on inventors' flow choice is positive and not significant ($\beta = 0.086$, $p > 0.05$). Models 4 confirms the positive and significant effect of haze pollution on inventors' flow choice to a city with better air quality ($\beta = 1.704$, $p < 0.001$), while Models 6 confirms the negative and significant effect of haze pollution on inventors' flow choice to a city with bad air quality ($\beta = -1.643$, $p < 0.001$).

Insert Table 1 and Table 2 about here

Urban Attraction, Haze Pollution and Inventors' Flow Choice

Table 3 depicts the logistic regression results of the moderate effect of *GDP gap* between departure and destination, and *urban patent application gap* between departure and destination. Model 7 show the moderate effect of *GDP gap* on the relationship between *haze pollution* and *inventors' flow choice* is positive and significant ($\beta = 0.552$, $p < 0.05$), while Model 9 show the moderate effect of *GDP gap* on the relationship between *haze pollution* and *inventors' flow choice to the city with better air quality* is positive and significant ($\beta = 0.865$, $p < 0.05$). Model 8 show the moderate effect of *urban patent application gap* on the relationship between *haze pollution* and *inventors' flow choice* is positive and not significant ($\beta = 0.074$, $p > 0.1$), while Model 10 show the moderate effect of *urban patent application gap* on the relationship between *haze pollution* and *inventors' flow choice to the city with better air quality* is positive and significant ($\beta = 0.189$, $p < 0.05$).

Insert Table 3 about here

Career Concern, Haze Pollution and Inventors' Flow Choice

Table 4 depicts the logistic regression results of the moderate effect of *firms' state ownership*, and *innovation ability of inventor*. Model 11 show the moderate effect of *state ownership* on the relationship between *haze pollution* and *inventors' flow choice* is positive and not significant ($\beta = 0.084$, $p > 0.1$), while Model 13 show the moderate effect of *state ownership* on the relationship between *haze pollution* and *inventors' flow choice to the city with better air quality* is negative and significant ($\beta = 0.044$, $p < 0.05$). Model 12 show the moderate effect of *innovation ability of inventor* on the relationship between *haze pollution* and *inventors' flow choice* is negative and not significant ($\beta = - 0.036$, $p > 0.1$), while Model 14 show the moderate effect of *innovation ability of inventor* on the relationship between *haze pollution* and *inventors' flow choice to the city with better air quality* is negative and significant ($\beta = - 0.057$, $p < 0.01$).

Insert Table 4 about here

Robust Test: Inventor Outflow at Firm Level

Thus far, we have documented evidence that local air pollution increases inventors' migration rate at the inventor-year level. In this section, we perform an analysis at the aggregated firm-year level. We investigate the impact of air pollution on the outflow of inventors to examine whether air pollution affects economic growth through innovation. To conduct the empirical test, we construct a new sample at the firm-year level, whereby for each firm-year, we count the number of inventors who leave the firm. We then construct the *Flow_firm* variable as a proxy for the outflow of inventors, which is defined as the number of outflowed inventors difference scaled by the total number of inventors in the firm at the beginning of the year.

After capturing an outflow of inventors due to air pollution, a follow-up question to consider is whether the outflow of inventors' results in a substantial decrease in firms' innovation outputs. To explore the economic outcome of inventor outflows in terms of firm innovation output, we regress firm innovation output on the outflow of inventors at the firm-year level. We introduce two measures to represent a firm's innovation output. The first is related to patent quantity and is measured by the number of patent applications that are eventually granted for the firm. The second reflects patent quality as measured by the number of firms' critical innovation as the following steps: First, for the measurement of year t, we identify all patents of a firm for between year t−4 and year t. Then, we filter the first three digits of the IPC number for all patents of the firm for this period. Next, we check if the first three digits of the IPC number of each patent existed in the preceding five years, including the current year and classify this patent as critical patents. Last, we use the natural logarithm of the number of critical patents as the measurement of firms' critical innovation.

Table 5 presents the regression results. The first column of Table 5 displays the impact of inventors' outflow on patent application quantities. Specifically, the coefficient estimates of *Inventors' outflow* is negative and significant at the 5% level, and the net outflow of inventors at the firm is associated with fewer patent applications. When considering the impact on firms' critical innovation, similar results are presented in the third column of Table 5. The evidence indicates that firms experiencing inventor losses exhibit poorer innovation output.

Discussion and Conclusion

In this paper, we examine the effect of haze pollution on inventor mobility. Based on an unbalanced panel dataset featuring with 128 cities, 1460 firms, and 34762 city-firm-inventors-year observations in the period from 2008 to 2019, we identify how environmental conditions influence talent mobility and the broader economic implications for innovation. We based on the logistic regression and present robust evidence that poor air quality prompts inventors to relocate to cities with better environments, affecting firms' innovation outputs. The study also considers the moderating roles of GDP gap between destination and departure, urban innovation vitality gap between destination and departure, state ownership, and inventors' patent output in these migration decisions. Overall, our paper offers novel evidence of the brain drain caused by haze pollution.

Theoretical Contributions

First, our study makes a significant contribution to the existing literature by exploring the impact of environmental externalities on economic growth through the lens of the brain drain effect. While many previous studies focus on firm-level factors influencing innovation (Balsmeier et al., 2017; Custodio et al., 2019; Manso, 2011), our research delves into the micro-level dynamics of inventor mobility. Specifically, we investigate how inventors, as key drivers of innovation, are prompted to migrate away from polluted areas, resulting in negative impacts on the innovation output of firms. By quantifying the sensitivity of inventor migration to air pollution, we provide empirical evidence on how environmental degradation can lead to a brain drain, which in turn, hinders a firm's innovative capacity. This adds a novel dimension to the understanding of the economic consequences of pollution, highlighting how it affects not just the environment, but also the talent pool critical for fostering innovation.

Second, building upon the literature on human capital migration due to air pollution (Chen et al., 2018; Levine et al., 2020; Xue et al., 2021), our study narrows the focus specifically to inventors, a highly specialized segment of the labor market. Given the crucial role inventors play in driving technological progress and economic growth, their migration patterns offer unique insights into the broader phenomenon of skilled labor movement. Our findings contribute to the growing body of research on the factors that influence inventor mobility (Akcigit et al., 2016; Chemmanur et al., 2019; Cheyre et al., 2015; Hombert & Matray, 2017; Palomeras & Melero, 2010), with air pollution emerging as a key driver. By concentrating on this highly skilled group, we deepen the understanding of how environmental factors, alongside traditional economic and career-related motivations, shape migration decisions. This focus provides valuable implications for policymakers aiming to retain talent in regions affected by pollution.

Third, our study introduces a more nuanced approach to analyzing the migration of inventors by considering several variables that are often overlooked in traditional research. We take into account the urban GDP gap and the city's innovation vitality as indicators of economic and innovation disparities between the destination and departure cities. Additionally, we explore the role of state ownership in firms and the patent output of inventors as indicators of career concerns when deciding whether to stay or migrate. This perspective distinguishes our research from most existing studies that treat pollution as a uniform factor (Chang et al., 2018; Dong et al., 2021). By incorporating these additional layers of complexity, we provide a more realistic and multifaceted analysis of how inventors respond to environmental degradation. This approach allows us to capture the intersection of economic, innovation-related, and career factors in shaping the migration patterns of highly skilled individuals, offering a more comprehensive understanding of the brain drain effect.

Practical Implications

The practical implications of this study are significant for policymakers, firms, and urban planners concerned with retaining and attracting high-skilled labor, particularly inventors. First, the findings suggest that environmental factors, such as air pollution, play a critical role in influencing the migration decisions of inventors, which can have detrimental effects on a firm's innovation capacity and, consequently, economic growth. Policymakers in polluted regions should prioritize environmental improvements not only to protect public health but also to retain key talent and sustain innovation. Investment in pollution reduction could help mitigate the brain drain effect and preserve the local economy's competitiveness in high-tech industries. Second, firms in pollution-prone areas must recognize the potential loss of innovation talent due to environmental degradation. Firms should consider implementing strategies to retain key inventors, such as offering relocation options to cities with better air quality or investing in remote work infrastructure. Additionally, firms could collaborate with local governments to support pollution control efforts, as maintaining a healthy environment is crucial for securing long-term innovation output and sustaining growth. Finally, urban planners and policymakers must consider the economic and innovation disparities between cities. Cities with stronger GDP and innovation vitality are more likely to attract inventors from polluted areas. To remain competitive, cities should focus on fostering an innovation-friendly environment by improving infrastructure, encouraging R&D investment, and supporting green technologies. By addressing both environmental and economic factors, cities can create ecosystems that not only attract but also retain high-skilled inventors, ensuring sustainable economic and innovation growth.

Limitations and Further Research

This paper has several limitations that present opportunities for future research. First, innovative talent in this study is measured using patent inventors' information, with their mobility tracked through the geographic data associated with patent applications. However, patent records do not disclose individual characteristics or demographic details of inventors, which may introduce omitted variable bias into the analysis. To address this limitation, future research could incorporate detailed surveys specifically targeting patent inventors to collect demographic data, enabling better control of individual-level variables and thus enhancing the robustness of the conclusions. Second, future studies could explore the impact of air pollution on the migration patterns of a broader spectrum of skilled workers within firms. Expanding the scope in this way would improve the generalizability and applicability of the findings across various types of talent.

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Table 1. Descriptive statistics and correlations

	Variable	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
01	Innovation talent flow	-															
02	Haze pollution	.633	-														
03	GDP growth gap	.195	.118	-													
04	Urban patent application gap	-.087	-.177	-.543	-												
05	State ownership	.023	.121	-.013	-.040	-											
06	Innovation ability of inventor	-.020	.042	-.029	-.018	.052	-										
07	Urban talent attention gap	.126	.098	.293	-.171	.023	.005	-									
08	Urban innovation index gap	.232	.177	.845	-.465	.001	-.031	.405	-								
09	Urban GDP growth	.023	.081	-.048	-.083	.084	.102	-.085	-.049	-							
10	Industry competition	.034	.003	-.041	.080	.078	-.087	-.014	.014	-.026	-						
11	Firm size	-.124	-.238	-.117	.187	.045	.034	-.031	-.151	-.053	.336	-					
12	Firm age	-.008	-.202	.019	.097	-.091	-.065	.022	-.057	-.140	.011	.410	-				
13	Firms' critical innovation	-.020	.039	.015	-.004	.122	.103	.014	.003	.027	-.005	.248	.070	-			
14	Number of inventors' patents	.003	-.015	.032	.041	-.033	.475	.005	.019	-.013	-.027	.087	.081	.128	-		
15	Number of inventors' patent citations	-.026	-.067	-.007	.103	.006	.475	-.006	-.033	-.068	.042	.212	.134	.182	.711	-	
16	Number of inventor teams	.050	.027	.101	-.154	.034	-.035	.051	.075	-.075	.025	.030	.161	-.070	-.009	-.042	-
	Mean	0.195	31.377	-218.92	8.953	0.0543	1.297	-2.99e-06	-32.244	10.399	0.113	23.398	16.360	1.253	0.769	2.123	1.471
	S.D.	0.396	10.291	11270.55	1.5603	.129	1.083	0.001	427.630	5.851	0.094	1.736	6.300	0.933	0.866	0.859	0.615
	Min	0	1.2	-35386.55	0	0	0	-0.001	-1933.433	-37.442	0.015	16.706	0	0	0	0	0
	Max	1	79.3	35386.55	11.467	0.971	8.129	0.001	1612.341	61.457	0.367	27.469	62	5.425	8.206	9.319	4.331

Notes: $^{*}p < 0.05$.

Table 2. Haze pollution and inventors' flow choice

	Dependent variable: Move		Dependent variable: Move to cities with good air quality		Dependent variable: Move to cities with bad air quality	
	Model 1	Mode 2	Model 3	Model 4	Model 5	Model 6
Haze pollution		0.086 (0.082)		1.704*** (0.044)		-1.643*** (0.046)
GDP growth gap	- 0.256***(0.057)	- 0.255*** (0.057)	- 0.256***(0.057)	- 0.370***(0.037)	- 0.256***(0.057)	0.285*** (0.036)
Urban patent application gap	0.200 (0.159)	0.206 (0.159)	0.200 (0.159)	- 0.293***(0.060)	0.200 (0.159)	0.342*** (0.082)
State ownership	0.111*** (0.034)	0.110*** (0.035)	0.111*** (0.034)	0.060***(0.019)	0.111*** (0.034)	- 0.029 (0.019)
Innovation ability of inventor	0.037 (0.031)	0.038 (0.031)	0.037 (0.031)	- 0.010 (0.020)	0.037 (0.031)	0.018 (0.020)
Urban talent attention gap	0.001 (0.032)	0.002 (0.033)	0.001 (0.032)	0.118*** (0.023)	0.001 (0.032)	- 0.122***(0.022)
Urban innovation index gap	- 0.545*** (0.055)	- 0.546*** (0.055)	- 0.545*** (0.055)	1.034*** (0.040)	- 0.545*** (0.055)	- 1.263*** (0.041)
Urban GDP growth	0.984*** (0.373)	1.025*** (0.375)	0.984*** (0.373)	0.649*** (0.208)	0.984*** (0.373)	0.060 (0.217)
Industry competition	0.101*** (0.031)	0.100*** (0.031)	0.101*** (0.031)	- 0.019 (0.018)	0.101*** (0.031)	0.096*** (0.018)
Firm size	0.262***(0.037)	0.262*** (0.037)	0.262***(0.037)	0.106***(0.022)	0.262***(0.037)	0.006 (0.022)
Firm age	-1.360*** (0.043)	-1.360*** (0.043)	-1.360*** (0.043)	- 0.262***(0.026)	-1.360*** (0.043)	- 0.304***(0.025)
Firms' critical innovation	0.110*** (0.027)	0.112*** (0.027)	0.110*** (0.027)	0.003 (0.017)	0.110*** (0.027)	0.052***(0.017)
Number of inventors' patents	- 0.199*** (0.033)	- 0.199*** (0.033)	- 0.199*** (0.033)	- 0.062***(0.021)	- 0.199*** (0.033)	- 0.020 (0.021)
Number of inventors' patent citations	0.125*** (0.034)	0.125*** (0.034)	0.125*** (0.034)	0.070*** (0.022)	0.125*** (0.034)	- 0.012 (0.021)
Number of inventor teams	0.126*** (0.025)	0.126*** (0.025)	0.126*** (0.025)	0.028* (0.016)	0.126*** (0.025)	0.025 (0.016)
Constant	7.369*** (0.391)	7.403*** (0.393)	7.369*** (0.391)	1.011*** (0.109)	7.369*** (0.391)	-0.417*** (0.131)
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes
City Dummy	Yes	Yes	Yes	Yes	Yes	Yes
lnsig2u	1.606*** (0.248)	1.606*** (0.249)	1.606*** (0.248)	-1.291***(0.199)	1.606*** (0.248)	-0.572*** (0.212)
Wald chi2	1891.99***	1892.78 ***	1891.99***	2787.93***	1891.99***	3503.60***

Notes: n (cities) = 128; n (observations) = 34,762; Numbers in parentheses are standard errors;
† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; two-tailed testsv

Table 3. Urban attraction, haze pollution and inventors' flow choice

	Dependent variable: Move		Dependent variable: Move to cities with good air quality	
	Model 7	Mode 8	Model 9	Model 10
Haze pollution	0.175** (0.087)	0.115 (0.087)	1.816*** (0.048)	1.702*** (0.044)
Haze pollution × GDP growth gap	0.552*** (0.037)		0.865*** (0.031)	
Haze pollution × Urban patent application gap		0.074 (0.067)		0.189*** (0.033)
GDP growth gap	- 0.436*** (0.057)	- 0.265*** (0.058)	- 0.932*** (0.046)	- 0.397*** (0.037)
Urban patent application gap	0.463*** (0.167)	0.291 (0.179)	- 0.280*** (0.063)	- 0.194*** (0.062)
State ownership	0.105*** (0.035)	0.108*** (0.035)	0.066*** (0.019)	0.059*** (0.019)
Innovation ability of inventor	0.035 (0.032)	0.038 (0.031)	- 0.018 (0.020)	- 0.013 (0.020)
Urban talent attention gap	0.024 (0.033)	0.002 (0.033)	0.173*** (0.024)	0.117*** (0.023)
Urban innovation index gap	- 0.381*** (0.056)	- 0.534*** (0.056)	0.173*** (0.024)	1.076*** (0.041)
Urban GDP growth	1.504*** (0.379)	0.934** (0.384)	0.662*** (0.214)	0.390* (0.214)
Industry competition	0.093*** (0.031)	0.103*** (0.031)	- 0.016 (0.019)	- 0.014 (0.018)
Firm size	0.261*** (0.037)	0.259*** (0.037)	0.102*** (0.023)	0.100*** (0.022)
Firm age	- 1.347*** (0.044)	- 1.359*** (0.043)	- 0.250*** (0.027)	- 0.265*** (0.026)
Firms' critical innovation	0.122*** (0.027)	0.113*** (0.027)	- 0.004 (0.017)	0.003 (0.017)
Number of inventors' patents	- 0.187*** (0.034)	- 0.199*** (0.033)	- 0.055** (0.022)	- 0.063*** (0.021)
Number of inventors' patent citations	0.113*** (0.034)	0.125*** (0.034)	0.071*** (0.022)	0.072*** (0.022)
Number of inventor teams	0.121*** (0.025)	0.125*** (0.025)	0.033** (0.016)	0.027* (0.016)
Constant	7.962*** (0.443)	7.439***(0.403)	1.054*** (0.114)	0.962*** (0.109)
Year Dummy	Yes	Yes	Yes	Yes
City Dummy	Yes	Yes	Yes	Yes
lnsig2u	1.899*** (0.250)	1.649*** (0.254)	- 1.045*** (0.206)	-1.287*** (0.202)
Wald chi2	2004.52 ***	1893.61***	2768.42***	2772.85***

Notes: n (cities) = 128; n (observations) = 34,762; Numbers in parentheses are standard errors;

$^{\dagger}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; two-tailed tests

Table 4. Career concern, haze pollution and inventors' flow choice

	Dependent variable: Move		Dependent variable: Move to cities with good air quality	
	Model 11	Mode 12	Model 13	Model 14
Haze pollution	0.084 (0.082)	0.098 (0.083)	1.703*** (0.044)	1.719*** (0.044)
Haze pollution ×State ownership	- 0.028 (0.038)		- 0.044* (0.023)	
Haze pollution ×Innovation ability of inventor		- 0.036 (0.026)		- 0.057*** (0.018)
GDP growth gap	- 0.254*** (0.057)	- 0.255*** (0.057)	- 0.370*** (0.037)	- 0.370*** (0.037)
Urban patent application gap	0.197 (0.160)	0.183 (0.160)	- 0.300*** (0.060)	- 0.305*** (0.060)
State ownership	0.120*** (0.037)	0.108*** (0.034)	0.075*** (0.020)	0.059*** (0.019)
Innovation ability of inventor	0.120*** (0.037)	0.046 (0.032)	- 0.011 (0.020)	0.011 (0.021)
Urban talent attention gap	0.001 (0.033)	- 0.000 (0.032)	0.116*** (0.023)	0.118*** (0.023)
Urban innovation index gap	- 0.547*** (0.055)	- 0.546*** (0.055)	1.035*** (0.040)	1.036*** (0.040)
Urban GDP growth	1.044*** (0.376)	1.041*** (0.375)	0.682*** (0.209)	0.663*** (0.208)
Industry competition	0.105*** (0.031)	0.102*** (0.031)	- 0.013 (0.018)	- 0.017 (0.018)
Firm size	0.259*** (0.037)	0.260*** (0.037)	0.105*** (0.022)	0.103*** (0.023)
Firm age	- 1.363*** (0.044)	- 1.361*** (0.043)	- 0.263*** (0.026)	- 0.263*** (0.026)
Firms' critical innovation	0.111*** (0.027)	0.112*** (0.027)	0.001 (0.017)	0.002 (0.017)
Number of inventors' patents	- 0.198*** (0.033)	- 0.200*** (0.033)	- 0.061*** (0.021)	- 0.062*** (0.021)
Number of inventors' patent citations	0.125*** (0.034)	0.124*** (0.034)	0.070*** (0.022)	0.068*** (0.022)
Number of inventor teams	0.127*** (0.025)	0.126*** (0.025)	0.028* (0.016)	0.028* (0.016)
Constant	7.403*** (0.393)	7.408*** (0.391)	1.016*** (0.109)	1.049*** (0.110)
Year Dummy	Yes	Yes	Yes	Yes
City Dummy	Yes	Yes	Yes	Yes
lnsig2u	1.601*** (0.249)	1.593*** (0.249)	-1.286*** (0.200)	-1.286*** (0.199)
Wald chi2	1893.87***	1894.74***	2787.18***	2784.27***

Notes: n (cities) = 128; n (observations) = 34,762; Numbers in parentheses are standard errors;

† $p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; two-tailed tests

Table 5. Inventors' outflow and firms' innovation output

	Dependent variable: Firms' patent application quantities		Dependent variable: Firms' critical innovation	
	Model 15	Mode 16	Model 17	Model 18
Inventors' outflow		- 0.670*** (0.102)		- 0.166** (0.068)
Firm size	0.036 (0.054)	0.034 (0.051)	0.026 (0.031)	0.026 (0.030)
Firm age	-3.103*** (0.191)	- 2.976*** (0.193)	- 1.810*** (0.160)	- 1.779*** (0.160)
State ownership$_{t-1}$	- 0.053* (0.028)	- 0.048* (0.027)	- 0.004 (0.019)	- 0.003 (0.019)
CEO age$_{t-1}$	- 0.006 (0.021)	- 0.005 (0.021)	0.005 (0.013)	0.005 (0.013)
CEO duality$_{t-1}$	0.012 (0.023)	0.014 (0.022)	0.004 (0.013)	0.004 (0.013)
Director independence$_{t-1}$	- 0.022 (0.035)	- 0.020 (0.034)	- 0.046* (0.024)	- 0.045* (0.024)
Financial leverage$_{t-1}$	- 0.591* (0.320)	- 0.648** (0.311)	- 0.425** (0.194)	- 0.439** (0.193)
Firm growth$_{t-1}$	- 0.000 (0.002)	- 0.000 (0.002)	- 0.001 (0.001)	- 0.001 (0.001)
Absorb slack$_{t-1}$	0.009 (0.014)	0.010 (0.015)	0.013*** (0.004)	0.013*** (0.004)
Potential slack$_{t-1}$	0.007 (0.018)	0.007 (0.018)	0.015 (0.009)	0.015* (0.009)
Cooperative patents$_{t-1}$	0.138*** (0.013)	0.130*** (0.012)	0.010 (0.009)	0.008 (0.009)
Constant	6.813*** (0.300)	6.492*** (0.306)	3.347*** (0.256)	3.268*** (0.257)
Year dummy	Yes	Yes	Yes	Yes
R-sq	0.352	0.368	0.395	0.402
F	23.94***	23.57***	12.81***	12.18***

Notes: n (firms) = 1473; n (observations) = 9335; Numbers in parentheses are standard errors;
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; two-tailed tests.