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Citation: Zheng, Siqi et al. "Air pollution and elite college graduates' job location choice: evidence from China." Annals of Regional Science 63, 2 (August 2019): 295–316 © 2019 Springer Nature

As Published: http://dx.doi.org/10.1007/s00168-019-00939-6

Publisher: Springer Science and Business Media LLC

Persistent URL: https://hdl.handle.net/1721.1/127801

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

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Cite this article as: Siqi Zheng, Xiaonan Zhang, Weizeng Sun and Chengtao Lin, Air pollution and elite college graduates' job location choice: evidence from China, The Annals of Regional Science https://doi.org/10.1007/s00168-019-00939-6

Air Pollution and Elite College Graduates' Job Location Choice: Evidence from China

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Air Pollution and Elite College Graduates' Job Location Choice: Evidence from China

Abstract: In this paper, we examine the impact of air pollution on the job location choice of a highly educated labor force. Using the administrative job contract records of all graduate students from Tsinghua University from 2005 to 2016, we find that air pollution significantly reduces the probability of elite graduates accepting job offers in a polluted city. Specifically, all else equal, if a city's $PM_{2.5}$ level increases by 10 μg/m^3, the share of Tsinghua graduates choosing that city will decrease by 0.23 percentage point (9% of the mean value). This "crowding-out" effect is larger for master's and doctoral graduates, but insignificant for undergraduates. A placebo test finds this effect does not exist for individuals who had signed a job contract prior to university admission, which strengthens our finding. Heterogeneity analysis indicates that males, students who grew up in cleaner provinces and students graduating from School of the Environment are more sensitive to air pollution. Different levels of preference for clean air and tolerance to pollution, as well as whether having the knowledge of pollution's harms, can effectively explain the heterogeneous effect of air pollution's impacts on job location choices of those elites.

Key words: air pollution; $PM_{2.5}$; elite graduates; job location choice

JEL Classification: Q53, Q56, R23

1. Introduction

Severe air pollution brings significant health and social costs to urban residents. Using data from different countries and regions, and focusing on a variety of pollutants (carbon monoxide, sulfur dioxide, nitrogen oxides, ozone, inhalable particulate matter and so on), researchers have found air pollution has significant negative impacts on people's health in both the short- and long-term, such as increased mortality (Dockery et al., 1993; Samet et al., 2000; Chay and Greenstone, 2003; Pope et al., 2011), reduced birth weight (Bobak, 2000; Currie and Neidell, 2005; Stieb et al., 2012), increased respiratory diseases and cardiovascular and cerebrovascular diseases (Schwartz and Morris, 1995; Wong et al., 1999; Dominici et al., 2006), and shortened life expectancy (Pope et al., 2009; Chen et al., 2013). Studies also find that air pollution tends to reduce people's life satisfaction (Welsch, 2002, 2006; MacKerron and Mourato, 2009; Luechinger, 2009, 2010; Li et al., 2014), and happiness (Levinson, 2012; Zhang et al., 2017; Zheng et al., 2019), and even to lead to mental disorders such as depression (Zhang et al., 2017). In a highly polluted country like China, some studies (Zheng et al., 2014; Sun et al., 2017) have already shown that people may elect to access real time air pollution information from modern media and adopt avoidance strategies to reduce pollution exposure. Among all population groups, elites with higher human capital have higher willingness to pay to avoid pollution. Various media outlets have reported that severe air pollution in China impedes cities' capacity to recruit and retain talent. Talented professionals (e.g., transnational company's executives) often hesitate to accept jobs in China due to concerns over air pollution and other quality of life issues. Local young college graduates also have become more selective when choosing where to work and live, preferring cities with cleaner air[1]. Many city leaders have recognized that blue sky has become their cities' core competence if they want to attract and retain talent. However, the underlying mechanism that determines how air pollution actually influences workers' (especially high-skilled workers') choice of job location, when workers have to make a tradeoff between job opportunities and quality of life, remains under-studied.

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[1] See reports in China Business Review (https://www.chinabusinessreview.com/air-pollution-impedes-executive-hiring-in-china/), Reuters (https://www.reuters.com/article/us-china-pollution-survey-idUSBREA2I0KU20140319) and Bloomberg (https://www.bloomberg.com/news/articles/2014-04-10/chinas-pollution-costs-companies-in-air-filters-employee-perks)

In this paper, we study the impact of air pollution on the job location choice of the highly educated labor force using a unique administrative data set of job contract data (2005-2016) for graduate students from Tsinghua University, one of China's top 2 universities. Since 2011, China's severe air pollution has attracted wide attention globally. Some young Beijing-based entrepreneurs are relocating their businesses to other cleaner cities, such as Hangzhou, Shenzhen and Shanghai[2]. They consider not only the negative impact of dirty air on their own health, but also the risk that their companies will lose talent if they choose to remain in cities, such as Beijing, where there is a low quality of life. When college graduates search for their first jobs, they also regard air quality as a key consideration when choosing which city to work in (and thus live in). To quantify this relationship, we merge air quality data gathered from remote sensing instruments with the job location (city) choice outcomes of Tsinghua graduates by geographic location from 2005 to 2016 to carry out our empirical research.

The job location decisions of college graduates allow us to more accurately identify the impact of urban livability characteristics such as air pollution. Compared with people who have lived in one place for a long time, college graduates face much lower relocation cost, so it is easier to disentangle the effect of air pollution from other factors influencing their job location choice. At the same time, graduates' job location decisions are mostly made about 9-12 months before their graduation, so we match their choices with the air pollution data at that decision-making time. Among all the universities in mainland China, Tsinghua University is ranked No. 1 in the QS World University Rankings. Those elite graduates have high income and also a strong demand for quality of life. Focusing on this subgroup of elite workers also offers us additional insight regarding how inflow and outflow of highly skilled labor force affects a city's economic growth potential. In addition to employment information, the dataset also includes many individual characteristics, including gender, major, degree received (undergraduate, master's, or PhD). This allows us to explore the heterogeneous effects of air pollution on the job location choice of graduates along multiple dimensions.

Based on the employment information of graduates, more specifically which

[2] See report: https://www.scmp.com/business/china-business/article/2059320/beijing-start-ups-move-out-hazardous-smog-smothers-capital.

cities their jobs are located, we calculate the proportion of Tsinghua graduates accepting job offers in each city for each year, and this yield a city-year panel data set. We will use both this panel data set and individual-level data of all graduates. In order to identify the casual effects of air pollution on job location choice, we introduce city fixed effects and year fixed effects, and control for city's time-variant local attributes in terms of economic development level, labor demand, living cost, public services and weather conditions. To address the potential endogeneity issue, we construct an instrumental variable for air pollution by taking advantage of cross-boundary spillovers of air pollution due to long-range transportability, which is widely used in the economic literature (Barwick et al., 2018; Williams and Phaneuf, 2016; Zheng et al., 2014).

We find that air pollution has a significantly negative effect on the probability of elite graduates accepting job offers in a city. All else equal, if $PM_{2.5}$ increases by 10 $\mu g/m^3$, the share of Tsinghua graduates accepting job offers in that city will decrease by 0.23 percentage point (mean: 2.69 percentage points, 9% of the mean value). This "crowding-out" effect is larger and more significant for graduate students than undergraduate students. The instrumental variable estimation yields similar results – the same direction of impact with a larger magnitude of coefficient than that in the OLS estimation. Our results are robust to various model specifications. Moreover, the placebo test further verifies our finding by showing no effect for those individuals who already signed job contracts prior to their admission to Tsinghua University (*ding xiang pei yang*). Finally, we also find significant heterogeneous effects among different groups. Males, Tsinghua Environmental School graduates, those who grew up in cleaner provinces, and those who major in engineering care more about the air quality of their future city of residence.

This study makes two main contributions to the literature. First, this is one of the few empirical studies that focuses on the impact of air pollution on job location choice, and thus adds to the growing literature that examines the determinants of job location choice across regions (So et al., 2001; Faggian et al., 2006; Wozniak, 2010; Plantinga et al., 2013). Using the national survey data on college graduates from 2012 to 2015 in China, Fan et al. (2018) investigates the impact of air pollution on the job location decisions of college graduates. Their results indicate that a ten-unit increase in $PM_{2.5}$ increases the probability of leaving the city by 6%. In this paper, we expand this research question by further examining the impact of air pollution on college graduates' job location choice for all optional cities following the framework of Rosen-Roback's spatial equilibrium theory. Second, this paper also contributes to the studies on the negative impact of air pollution on local economy. Existing papers have found negative effects of air pollution on labor supply (Hanna and Oliva, 2015; Zhang et al., 2018), labor productivity (Graff and Neidell, 2012; Li et al., 2015; Chang et al., 2016) and academic outcomes (Currie et al., 2009; Stafford, 2015). This paper thus adds to the literature by associating air pollution with a new perspective – the city's power to retain and attract talent, which has been shown to have significant and positive effects on economic development (McAusland and Kuhn, 2011; Vandenbussche et al., 2006; Whalley and Zhao, 2013).

The rest of the paper is organized as follows. In section 2, we present the identification strategies and introduce the data. Sections 3 and 4 provide the main empirical results, robustness and placebo tests, and heterogeneous analysis. We conclude the paper in section 5.

2. Empirical Strategy

2.1 Model specifications

Binary location decision model

As Tsinghua University is located in Beijing, we adopted a linear probability model (LPM) that uses individual level data to test the effect of Beijing's air pollution on graduates' choice of whether to stay in Beijing. The model specification is as follows:

$$choice_{it} = \alpha_1 \cdot relative\_pm_{t\text{-}1} + \boldsymbol{\alpha}_2 \cdot \mathbf{X}_{t\text{-}1} + \boldsymbol{\alpha}_3 \cdot \mathbf{Y}_{it} + \varepsilon_i \qquad (1)$$

where $choice_{it}$ equals 1 if student i chooses to stay in Beijing after graduation in year t. $relative\_pm_{t\text{-}1}$ measures the ratio of Beijing's average $PM_{2.5}$ concentration in year t-1 to the mean value of other large and medium-sized cities in China[3]. Here we use this relative level indicator, because the job location choice decision is affected by how severe Beijing's air pollution is, compared with other major cities. Such a "relative"

[3] There are 35 large and medium-sized cities in China, including Beijing, Tianjin, Shijiazhuang, Taiyuan, Huhehaote, Shenyang, Dalian, Changchun, Harbin, Shanghai, Nanjing, Hangzhou, Ningbo, Hefei, Fuzhou, Xiamen, Nanchang, Jinan, Qingdao, Zhengzhou, Wuhan, Changsha, Guangzhou, Shenzhen, Nanning, Haikou, Chongqing, Chengdu, Guiyang, Kunming, Xi'an, Lanzhou, Xining, Yinchuan, Urumqi. During our study period, more than 94% of Tsinghua graduates chose to work in one of the large and medium-sized cities in China, which means elite graduates seldom select to work in small cities, and thus we set the large and medium-sized cities as their potential working places.

level cannot be fully reflected by the absolute value of concentration. Similarly, we also construct such relative level indicators for Beijing's other attributes, $\mathbf{X}_{t\text{-}1}$, measured as the ratio of Beijing's GDP per capita, population, the number of high schools per capita, etc., to the mean value of those indicators, respectively, in other large and medium-sized cities[4]. $\mathbf{Y}_{it}$ controls for student characteristics, including gender, ethnicity, degree and a set of college department dummy variables and home province dummy variables. Department dummies are added to control major-specific fixed effects. Home province dummies are used to control for the "hometown effect", which takes into consideration that students from certain provinces are more likely to return to their hometown after graduation. To examine the impact of distance between students' home province and Beijing on the location choice, we use this distance measure instead of home province dummy in some regressions. To deal with the potential problems of serial correlation, we clustered standard errors according to students' home province[5].

City level choice model

Besides the binary choice of whether to stay in Beijing (where Tsinghua University is located), a graduate also must decide which specific city he/she will work in, from a menu of many different cities. A panel-data model is adopted to test the effect of a destination city's air pollution on graduates' probability of accepting job offers in that city. The model specification is as follows:

$$share_{jt} = \alpha_1 \cdot pm_{jt\text{-}1} + \alpha_2 \cdot share_{jt\text{-}2} + \boldsymbol{\alpha}_3 \cdot \mathbf{X}_{jt\text{-}1} + \alpha_4 \cdot w_t + \alpha_5 \cdot \mu_j + \qquad (2)$$

where $share_{jt}$ refers to the share of students who accept job offers in city j among all students who graduated in year t. $pm_{jt\text{-}1}$ measures city j's average $PM_{2.5}$ concentration in year t-1. In this city level choice model, we model the choice of the destination city among all potential cities. We are not comparing Beijing with others, instead, we are comparing between those potential cities. Therefore, the absolute air pollution level of each city is an appropriate measure to this purpose. We also include $share_{jt\text{-}2}$ on the right hand side to control for the cohort network effect, considering later graduates are

[4] We also use the ranks of PM2.5 as well as other economic variables of Beijing among the 35 large and medium-sized cities in the graduates' location choice model, the results are consistent with those using the relative level indicators.

[5] We also try to cluster the standard errors by students' department (also major) as a robustness check. The results are consistent with the results when clustering the standard errors at the home province level.

influenced by earlier cohorts' job location choices[6]. $\mathbf{X}_{jt-1}$ refers to city j's economic and population attributes, as well as weather attributes. The economic and population attributes include GDP per capita, GDP shares of secondary industry and tertiary industry, total population, housing price, Bartik index, as well as the number of primary schools and doctors per capita. The weather variables include average temperature, total precipitation, and the number of days with snow, with storm, with fog and with frost. ω_t refers to year dummies, which capture changes in labor demand due to business cycles. μ_j refers to city dummies, which control for cities' time-invariant attributes.

IV design

The negative relationship between $PM_{2.5}$ concentration and the probability that students choose the city may be generated by omitted factors that vary with years on the level of individual cities. For example, industrial upgrades may cause changes in air pollution and also increase student attraction to a city. In this case, our estimates would be biased in favor of the direct role of pollution in causing a low share of graduates to elect to move to the city. We employ an instrumental variable (IV) approach to address this potential endogeneity issue.

We utilize air pollution from the cities in the upwind direction to construct the instrumental variable. As the wind blows air pollutants from upwind cities to the destination city, this introduces exogenous variation in the destination city's air pollution (Zhang et al., 2017). This exogenous variable is unlikely to affect the destination city's local social and economic activities through other channels, so it is an ideal instrumental variable (Bayer et al., 2009; Zheng et al., 2014). Drawing from the method adopted by Barwick et al. (2018), we construct our IV as follows:

$$IV_{it} = \sum_j \max(\cos\theta_{ij}, 0) \times PM_{2.5jt} / e^{d_{ij}}\ ,\ 60km < d_{ij} < 300km \qquad (3)$$

where $PM_{2.5jt}$ is city j's $PM_{2.5}$ concentration in year t. θ_{ij} denotes the angle between the wind direction of city i and the direction from city j to city i. We make a simple vector decomposition and assume that the amount of pollutants carried toward city i from city j is the larger one between $\cos(\theta_{ij})$ and zero. d_{ij} is the distance (in hundred km) between local city i and city j. Considering agglomeration economies will lead to the correlation

[6] The choice of cohort that is just one year earlier, $share_{jt-1}$, is not used because it is also highly influenced by the pm_{jt-1}. For samples in 2005/2006, we use the average share in the whole study period as the two-year-lag choice share.

or co-movement of nearby cities' local economies, we exclude all cities within 60 km from local city i in the equation. Also, cities that are too far from local city i, setting 300km as the cutoff, are not included in the calculation[7].

Refer to Figure 1 to understand the construction of IV more directly. City A in the middle is our destination city, with its wind direction from the north. The angle between the wind direction of city A and the location of city B, θ_{ab}, is smaller than 90°, so that the contribution of air pollution from city B to our IV is $\cos\theta_{ab} \times PM_{2.5bt}/e^{d_{ab}}$. Similarly, city C contributes $\cos\theta_{ac} \times PM_{2.5ct}/e^{d_{ac}}$. As θ_{ac} and d_{ac} is larger than θ_{ab} and d_{ab} respectively, the air pollution of city C has less effect on city A. Given that θ_{ad} is larger than 90°, $\cos\theta_{ad}$ is less than 0 and therefore city D will be excluded in the IV calculation. In addition, city E and F are not included because they are either too near or too far.

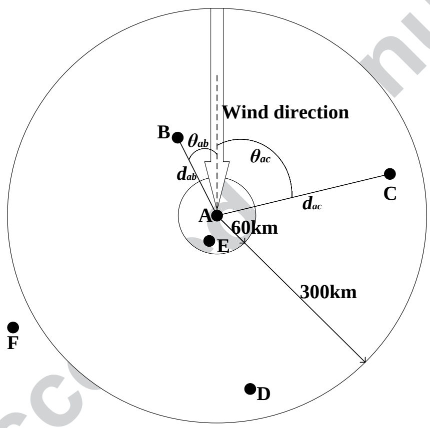

Figure 1. Construction of instrumental variable

2.2 Data

Our primary dataset is administrative data from Tsinghua University Graduates Employment Record 2005–2016. Established in 1911, Tsinghua University is located in Beijing, China's capital. It has been consistently ranked first among all mainland Chinese universities on the QS Global University Rankings over the last 5 years.

The dataset includes every student who graduated from Tsinghua University between 2005 and 2016. In this study, we focus on those students who accepted a job offer upon graduation. The key information for such students contains their graduation year, school, degree received (bachelor's, master's, or PhD), and the city where they took employment. In addition, the data contain basic demographic

[7] As for the choice of cutoffs (60km and 300km), we refer to the study of Fan et al. (2018). We also tried different distances and the results are robust.

information, such as gender, ethnic minority or not, and hometown province (where students attend the college entrance examination).

In addition, we divide students into two sub-samples, depending on whether they already had a labor contract prior to their admission to Tsinghua University (*ding xiang pei yang*). For those with contracts, jobs are determined prior to entering the university, and their tuition is usually paid by their employers. We exclude these students in the main analysis because they do not search for jobs when they graduate. The placebo test is conducted based on such students.

As for the main explanatory variable, we apply satellite-derived $PM_{2.5}$ concentrations across China for the period from 2004–2016 as developed by Van Donkelaar et al. (2015). By using ArcGIS, the 0.1°×0.1° grid-level $PM_{2.5}$ concentrations are collapsed to the city level. Compared to air pollution levels recorded by monitoring stations, the satellite-derived data has better temporal and spatial coverage and is more objective and accurate (Ghanem & Zhang, 2014). Further, it also matches well with station data (Gupta et al., 2006; Kumar et al., 2015).

Our secondary data is city-level statistics. The economic and population attributes come from China City Statistical Yearbooks. Referring to Bartik (1991) and Wozniak (2010), we construct a Bartik index, an indicator of exogenous labor demand shock for each city in each year, as follows.

$$bartik_{jt} = \sum_{d=1}^{D} e_{jd,t\text{-}1}(\ln \tilde{E}_{dt} - \ln \tilde{E}_{d,t-1}) \quad (4)$$

where d indexes industry, j city, and t year. $e_{jd,t\text{-}1}$ is the share of employment for city j in industry d in year t-1. $\tilde{E}_{dt}$ is the national employment level in industry d excluding city j and $\tilde{E}_{d,t-1}$ is the same measure but in the previous year. Therefore, the term in parentheses is a measure of national employment growth in industry d except for city j. The sum of industry-level products is a proxy for changes in city level employment driven by industry growth outside the city. Employment data also comes from China City Statistical Yearbooks, which covers 19 industries in total.

Station level weather data comes from http://www.meteomanz.com/. By linking each city with the nearest weather station, we obtain city-level weather attributes. Tables 1 and 2 present the variable definitions and summary statistics for the linear probability model and panel model, respectively. According to the summary statistics, from 2005 to 2016 about 60% of graduates from Tsinghua University ultimately chose to work in Beijing.

Table 1. Variable definitions and summary statistics for linear probability model

Variables	Definition	Obs.	Mean	Std.	Min.	Max.
choice	Whether graduates chose to stay in Beijing (stay=1; leave=0)	34,828	0.60	0.49	0	1
relative_pm	The ratio of Beijing's $PM_{2.5}$ concentration to other large and medium-sized cities' average level	34,828	1.16	0.07	1.00	1.28
gender	Male=1; female=0	34,828	0.68	0.47	0	1
ethnicity	Minority=1; other=1	34,828	0.07	0.25	0	1
degree	Bachelor=0; master=1; doctor=2	34,828	1.05	0.60	0	2
log_dhome	The logarithm of the distance between graduates' home province and Beijing	34,828	5.95	2.17	0	7.88
relative_gdppc	The ratio of Beijing's GDP per capita to other large and medium-sized cities' average level	34,828	1.43	0.12	1.26	1.60
relative_pop	The ratio of Beijing's population to other large and medium-sized cities' average level	34,828	1.83	0.03	1.81	1.92
relative_highsch	The ratio of Beijing's high schools per capita to other large and medium-sized cities' average level	34,828	1.12	0.07	1.01	1.22

Table 2. Variable definitions and summary statistics for panel model

Variables	Definition	Obs.	Mean	Std.	Min.	Max.
shareall	The share of all graduates that accept job offers in the city (%)	419	2.69	9.99	0	66.45
shareunder	The share of undergraduate students that accept job offers in the city (%)	419	2.55	8.36	0	60.90
sharegradu	The share of graduate students that accept job offers in the city (%)	419	2.72	10.36	0	71.01
pm	$PM_{2.5}$ concentration in the year before graduation ($\mu g/m^3$)	419	44.27	15.42	14.88	88.91
gdppc	GDP per capita (10 million RMB)	419	55.16	36.36	8.48	467.75
second_gdp	The share of secondary industry by GDP (%)	419	45.39	7.83	19.25	61.59
third_gdp	The share of tertiary industry by GDP (%)	419	49.44	8.35	34.93	79.65
pop	Total population at the end of year (10 million)	419	0.70	0.54	0.14	3.38
resihp	Residential housing price (10,000 RMB / m^2)	419	0.61	0.42	0.14	3.37
bartik	Bartik index	419	0.05	0.07	-0.08	0.32
primsch	Number of primary schools per 10,000 people	419	1.50	0.72	0.38	3.59
doctor	Number of doctors per 10,000 people	419	31.18	13.68	11.64	88.45
temp	Average temperature (^{o}C)	419	15.06	5.36	4.5	26
prec	Total precipitation (mm)	419	944.21	516.43	76.5	2687.8
dayssnow	The number of days with snow	419	15	16.70	0	79

daysstorm	The number of days with storm	419	28.44	20.67	0	91
daysfog	The number of days with fog	419	23.13	26.04	0	156
daysfrost	The number of days with frost	419	66.80	61.67	0	180

3. Main Results

3.1 Whether to stay in Beijing

We utilize the probability model in regression model (1) to examine the effect of Beijing's air pollution on students' choice to stay in Beijing. Estimate results are reported in Table 3. In the first three columns, we include the distance between the graduate's home province and Beijing, instead of hometown fixed effects. In column (1) & (4), we find negative estimates of coefficient of Beijing's relative $PM_{2.5}$ concentration compared to other large and medium-sized cities, which is statistically significant at the 1% level. This means that when Beijing's air pollution is much worse than that for other major cities (so a higher relative ratio) it significantly reduces the likelihood that students choose to stay in Beijing after graduation. Specifically, if the ratio of Beijing's $PM_{2.5}$ concentration to other large and medium-sized cities' average level increase by 0.1, which indicates worse air quality compared to other cities, will decrease the probability of staying in Beijing by 0.7 percentage point (mean: 60 percentage points, 1.2% of the mean value). This negative effect is even larger for graduate students, which is shown in column (3) & (6). As for undergraduate students, the effect is not significant and much smaller (column (2) & (5)). One possible explanation for this is that the primary choice of undergraduate students from Tsinghua University is to pursue a graduate program rather than directly entering the job market. The sample of undergraduates in our study is much smaller than the sample of graduates, which may not be large enough to test the effect of air pollution.

Table 3. The effect of Beijing's air pollution on choice to stay in Beijing

	(1) Total	(2) Undergraduates	(3) Graduates	(4) Total	(5) Undergraduates	(6) Graduates
relative_pm	-0.0733***	-0.0118	-0.0581**	-0.0733***	-0.0121	-0.0581**
	(0.0176)	(0.0854)	(0.0246)	(0.0176)	(0.0853)	(0.0246)
gender	-0.0654***	-0.0678***	-0.0613***	-0.0655***	-0.0682***	-0.0613***
	(0.00561)	(0.0111)	(0.00675)	(0.00561)	(0.0111)	(0.00675)
ethnicity	-0.0206***	-0.00352	-0.00700	-0.0205***	-0.00297	-0.00700
	(0.00725)	(0.0170)	(0.0118)	(0.00725)	(0.0170)	(0.0118)
degree	0.100***		0.0637***	0.100***		0.0637***
	(0.00917)		(0.0110)	(0.00916)		(0.0110)
d_home	-0.0369***	-0.0498***	-0.0361***			
	(0.00117)	(0.00367)	(0.000613)			
relative_gdpp	0.0893*	0.143	0.0244	0.0892*	0.143	0.0244
	(0.0487)	(0.0912)	(0.0370)	(0.0487)	(0.0911)	(0.0370)

relative_pop	0.249*	-0.294	0.470***	0.249*	-0.291	0.470***
	(0.124)	(0.231)	(0.126)	(0.124)	(0.231)	(0.126)
relative_highsch	0.537***	-0.966***	0.855***	0.537***	-0.966***	0.855***
	(0.0815)	(0.273)	(0.0815)	(0.0814)	(0.273)	(0.0815)
relative_midsch	0.00289	-0.132	0.479***	0.00393	-0.125	0.479***
	(0.348)	(0.465)	(0.161)	(0.347)	(0.466)	(0.161)
Department fixed effects	YES	YES	YES	YES	YES	YES
Hometown fixed effects	NO	NO	NO	YES	YES	YES
N	34824	5281	29543	34828	5284	29544
R^2	0.138	0.211	0.137	0.138	0.211	0.137

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. There are four students not from mainland China and we don't have the detailed information to calculate the distance between their home to Beijing. Therefore, the sample size in column (1) are less than that in column (4).

The coefficients of demographic variables and city-level attributes are also reasonable. The coefficient of the distance variable is significantly negative, indicating that if the student's home province gets farther from Beijing, (s)he will have a lower likelihood of choosing to stay in Beijing. Female students, nonminority students, and graduates with higher degrees are more likely to accept a job offer in Beijing. Meanwhile, if the relative level of Beijing's GDP per capita, population, as well as the number of high schools per capita gets larger, which indicate the condition of Beijing in those aspects gets relatively better compared to other large and medium-sized cities, the probability that students choose to stay in Beijing will increase[8].

3.2 Choosing among 35 large and medium-sized cities

Table 4 reports the estimated results of equation (2) and IV regressions. Similar to results found in Table 3, having a higher level of air pollution is found to have a significantly negative effect on the probability of elite graduates accepting a job offer in a city. If a city's $PM_{2.5}$ level increases by 10 μg/m^3, the share of Tsinghua graduates choosing that city will decrease by 0.23 percentage point (mean: 2.69 percentage points, 9% of the mean value). The crowding-out effect is found to be larger and more significant for graduate students than for undergraduate students. When including the instrument variable, the estimation results are similar in direction of influence but larger in magnitude than those in OLS estimations. As air pollution may result from an extensive secondary industry and indicate higher output and higher income, such omitted variables will increase the probability that students choose to work in polluted cities. Therefore, the OLS estimation is biased to the lower bound, and IV results are

[8] We calculate the variance inflation factors (VIFs) for independent variables, which are all less than 3, thus indicating there is little risk of multicollinearity in this model.

larger in magnitude and closer to the direct effect of air pollution. The first-stage regression indicates that the instrumental variable, air pollution from upwind cities, has strong explanatory power on the destination city's air pollution. Further, the large Cragg-Donald Wald F statistic (41.60) indicates that the instrument is acceptable (not weak)[9]. Besides, we find that the cohort network effect is significant in all regressions. Consistent with our expectation, later graduates are influenced by earlier cohorts' job location choices. If two years ago, the share of Tsinghua graduates choosing that specific city is larger by 1 percentage point (relative to the default city), the share of fresh graduates choosing that city is also larger by about 0.27-0.44 percentage point (relative to the default city) in the current year.

Table 4. The effect of air pollution on choice between cities

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependents:	*shareall*	*shareunder*	*sharegradu*	*shareall*	*shareunder*	*sharegradu*
pm	-0.0228***	-0.00886	-0.0286***	-0.0517**	0.0372	-0.0682**
	(0.00843)	(0.0143)	(0.0102)	(0.0254)	(0.0424)	(0.0308)
share_lag	0.419***	0.270***	0.442***	0.407***	0.274***	0.430***
	(0.0509)	(0.0624)	(0.0513)	(0.0506)	(0.0609)	(0.0511)
City attributes	YES	YES	YES	YES	YES	YES
Weather attributes	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
N	419	419	419	419	419	419
R^2	0.460	0.136	0.523	0.442	0.110	0.502
First-stage regression						
IV				0.143***	0.144***	0.143***
				(0.0221)	(0.0221)	(0.0221)
Cragg-Donald Wald F statistic				41.60	42.97	41.50

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

3.3 Robustness Tests

In the main regression, we utilize $PM_{2.5}$ concentration in the year before graduation as the indicator of a city's air pollution level. As $PM_{2.5}$ has become the primary air pollutant in China in recent years, the number of news reports and people's awareness about its negative health effects have increased rapidly. Therefore, we can reasonably assume that students will take $PM_{2.5}$ concentration into consideration when they are searching for jobs, which occurs at the end of the year before they graduate. To verify the effect is not limited to $PM_{2.5}$ itself, but the air pollution level of target cities, the concentration of SO_2 is used as another main air pollutant in columns (1) - (3) in Table 5. The responses of graduates from bachelor, master's and doctoral degrees are tested separately in each column. In addition,

[9] Stock and Yogo (2005) estimate the critical value of the Cragg–Donald statistic to be equal to 16.38 for a model with one endogenous regressors and one instrument.

considering the fact that some students make their final job decisions during their graduation year, we also use the $PM_{2.5}$ concentration in the graduation year in place of the year before graduation. These results are reported in columns (4) - (6) in Table 5. The results are very robust, showing that on average air pollution has a significant negative effect on college graduate students' job location choice, and the effect is larger for students with master's or PhD degrees but not significant for undergraduates.

Table 5. Robustness check for panel model

	(1)	(2)	(3)	(4)	(5)	(6)
Dependents:	*shareall*	*shareunder*	*sharegradu*	*shareall*	*shareunder*	*sharegradu*
SO_2	-0.0488***	-0.0138	-0.0574***			
	(0.0143)	(0.0243)	(0.0172)			
pm_gra				-0.0169**	0.0107	-0.0258**
				(0.00849)	(0.0142)	(0.0103)
share_lag	0.404***	0.270***	0.429***	0.419***	0.269***	0.441***
	(0.0512)	(0.0633)	(0.0516)	(0.0514)	(0.0621)	(0.0519)
City attributes	YES	YES	YES	YES	YES	YES
Weather attributes	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
N	416	416	416	419	419	419
R^2	0.468	0.136	0.528	0.447	0.136	0.510

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

3.4 Placebo Test

In this study, we consider air pollution to be an important determinant in college graduates' job location choice. Through including sufficient control variables and using the IV approach, we have found robust causal effects of air pollution on college graduates' job location decision. In this part, we further conduct a placebo test on samples who already had labor contracts prior to their admission to Tsinghua University (*ding xiang pei yang*). As *ding xiang pei yang* students' jobs are determined prior to entering the university and they have much higher cost to change their jobs after graduation[10], we expect air pollution to have no effect on their job location choice. If that is not the case, it might imply an illusory effect of air pollution on college graduates' job location choice. The estimated results are reported in Table 6. Both OLS and IV estimates show insignificant results, which is consistent with our expectation. This placebo test further verifies that a higher level of air pollution influences the graduates' job location choice behavior.

[10] If *ding xiang pei yang* students refuse to comply with the contract after graduation, they will be charged a high penalty, which is double the amount of the subsidy received during their whole study period. Further, they cannot receive their diploma from Tsinghua University and cannot register for graduation information online for five years.

Table 6. Placebo test on *ding xiang pei yang* students

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependents:	*shareall*	*shareunder*	*sharegradu*	*shareall*	*shareunder*	*sharegradu*
pm	-0.0386	-0.0404	-0.0111	-0.0185	-0.0302	0.00703
	(0.0231)	(0.0290)	(0.0241)	(0.0484)	(0.0835)	(0.0708)
share_lag	0.159	0.165^{***}	0.0754	0.159^{***}	0.165^{***}	0.0766
	(0.124)	(0.0591)	(0.0547)	(0.0499)	(0.0566)	(0.0527)
City attributes	YES	YES	YES	YES	YES	YES
Weather attributes	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
N	419	383	419	419	383	419
R^2	0.432	0.295	0.205	0.430	0.295	0.203
First-stage regression						
IV				0.144^{***}	0.144^{***}	0.146^{***}
				(0.0221)	(0.0227)	(0.0221)
Cragg-Donald Wald F statistic				42.69	39.91	42.36

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4. Heterogeneity Analysis

4.1 Heterogeneous effects among student groups

Thus far, we have found that on average air pollution significantly affects college graduates' job location choice. For different student groups, the degree they care about air pollution may vary according to their personal preference, knowledge about air pollution and so on. To test the heterogeneous effects, we divide the whole sample into groups by gender, the air quality of their hometown, the school they graduated from and the major they studied. Table 7 presents the OLS estimates for each group, which illustrates that males, graduates coming from cleaner provinces, those graduating from environmental school and students majoring in engineering and art care more about the air quality of destination cities. The results are consistent with our expectation. While both are significant, the coefficients are larger for males than for females, which indicates males are more sensitive to air pollution when making location choice. Students from polluted hometowns are more accustomed to poor air quality and have lower sensitivity than those from cleaner hometowns. Those graduating from environmental schools know more about the negative effects of air pollution and thus have a stronger preference for cleaner cities. Tsinghua University has an unbalanced composition of majors. In the whole sample, the ratio of graduates majoring in engineering, art and science is about 10:6:1. The limited number of students majoring in science can explain why the estimated result for this group is less significant. The IV estimates for different groups can be found in Appendix Table 1. Based on these heterogeneous effects, it can be expected that being accustomed to air pollution and recognizing the harm of air pollution could determine job location choice for elites given differing levels of air pollution.

Table 7. Heterogeneous effects between different students-OLS estimates

	(1) Males	(2) Females	(3) Polluted hometown	(4) Clean hometown	(5) Environmental School	(6) Other schools	(7) Engineering	(8) Art	(9) Science
Panel A: All graduates									
pm	-0.0256***	-0.0225**	-0.0141*	-0.0327***	-0.0608**	-0.0218***	-0.0259***	-0.0262**	-0.0147
	(0.00901)	(0.00967)	(0.00834)	(0.0113)	(0.0253)	(0.00838)	(0.00958)	(0.0109)	(0.0180)
share_lag	0.373***	0.466***	0.0209	0.432***	0.144***	0.407***	0.503***	0.0485	0.320***
	(0.0514)	(0.0518)	(0.0548)	(0.0532)	(0.0530)	(0.0517)	(0.0507)	(0.0565)	(0.0525)
N	419	419	419	419	419	419	419	419	419
R^2	0.434	0.472	0.152	0.472	0.266	0.448	0.507	0.166	0.308
Panel B: Undergraduates									
pm	-0.00645	-0.0179	-0.00334	0.0150	-0.0156	-0.00836	-0.00457	-0.0334**	0.0418
	(0.0156)	(0.0192)	(0.0151)	(0.0199)	(0.0572)	(0.0140)	(0.0189)	(0.0160)	(0.0383)
share_lag	0.301***	0.0591	0.119**	0.252***	-0.412***	0.292***	0.357***	0.0141	-0.136**
	(0.0623)	(0.0593)	(0.0563)	(0.0629)	(0.0518)	(0.0630)	(0.0633)	(0.0567)	(0.0562)
N	419	419	419	419	419	419	419	419	419
R^2	0.176	0.065	0.092	0.221	0.195	0.144	0.136	0.087	0.142
Panel C: Graduates									
pm	-0.0327***	-0.0254**	-0.0155*	-0.0417***	-0.0632**	-0.0276***	-0.0335***	-0.0267**	-0.0254
	(0.0112)	(0.0108)	(0.00863)	(0.0137)	(0.0255)	(0.0101)	(0.0114)	(0.0121)	(0.0188)
share_lag	0.401***	0.488***	0.159***	0.476***	0.271***	0.432***	0.548***	-0.00280	0.427***
	(0.0511)	(0.0538)	(0.0544)	(0.0524)	(0.0527)	(0.0520)	(0.0501)	(0.0571)	(0.0491)
N	419	419	419	419	419	419	419	419	419
R^2	0.505	0.493	0.298	0.538	0.349	0.514	0.573	0.188	0.485

Note: (1) Control variables include city attributes, weather attributes, city fixed effects, and year fixed effects. (2) Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2 Heterogeneous effects between different levels of information transparency

Since 2011, air pollution has received much attention in China, and this attention has been reflected by more and more news reports about air pollution. We collect the number of news reports for each city and each year with the key words "haze" or "$PM_{2.5}$" in Baidu, the main search engine in China. By interacting $PM_{2.5}$ with this variable, we test how information transparency regarding air pollution influences students' choice. As shown in Table 8, the interaction term is significantly negative for all students and graduates. This indicates that given the $PM_{2.5}$ concentration level, more new reports will further lower the probability that a city is chosen. This means better information transparency will improve students' knowledge of air pollution in target cities, and further influence their decision choice.

Table 8. Heterogeneous effects between different levels of information transparency

Dependents:	(1) *shareall*	(2) *shareunder*	(3) *sharegradu*
pm	-0.0205**	-0.0228*	-0.0227**
	(0.00947)	(0.0132)	(0.0115)
*pm*reports*	-0.00519**	-0.0769***	-0.00882***
	(0.00225)	(0.0137)	(0.00273)
City attributes	YES	YES	YES
Weather attributes	YES	YES	YES
City fixed effects	YES	YES	YES
Year fixed effects	YES	YES	YES
N	419	419	419

R^2	0.365	0.234	0.435

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3 Heterogeneous effects among different years

Considering economic agents always behave in a forward-looking way, their response to air pollution may change with time. In Table 9, we try to identify the time trend from our data. The interaction term is significantly positive for all students and graduates, thus indicating that students are becoming less sensitive to air pollution over time. The result is consistent with the finding of Nam et al. (2019). This may be partly due to the Chinese government's strong signal to the market on strict pollution regulations. The signal then gives residents an impression that air pollution in urban areas will sooner or later be less of a concern, leading to reduced sensitivity.

Table 9. Heterogeneous effects between different years

Dependents:	(1) *shareall*	(2) *shareunder*	(3) *sharegradu*
pm	-3.628**	2.051	-4.930**
	(1.672)	(2.685)	(2.036)
pm**year*	0.00179**	-0.00102	0.00243**
	(0.000831)	(0.00133)	(0.00101)
City attributes	YES	YES	YES
Weather attributes	YES	YES	YES
City fixed effects	YES	YES	YES
Year fixed effects	YES	YES	YES
N	419	419	419
R^2	0.364	0.095	0.428

Note: Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Conclusion

In this paper, we study the impact of air pollution on elite college graduates' job location choice in China. By merging air quality data from remote sensing with a unique administrative dataset including all recent graduate students' job contract data from Tsinghua University in China from 2005 to 2016, we construct a city-year panel dataset to examine the causal relationship between air pollution and graduate students' job location choice. We find that severe air pollution has a significantly negative impact on a city's power to retain and attract top talent. Specifically, 0.1 unit increase in the ratio of Beijing's $PM_{2.5}$ concentration to other large and medium-sized cities' average level, which indicates Beijing air quality getting worse compared to other cities, will decrease the probability of staying in Beijing by 0.7 percentage point (mean: 60 percentage points, 1.2% of the mean value). If we consider all the 35 large and medium-sized cities as optional job locations, a 10 $\mu g/m^3$ increase in annual average $PM_{2.5}$ concentration will decrease the share of Tsinghua graduates choosing that city by 0.23 percentage point (mean: 2.69 percentage points, 9% of the mean value). This negative effect is found to be even larger for master's and doctoral graduates, but insignificant for undergraduates. Moreover, male graduates are more sensitive to air pollution than female graduates; students coming from cleaner provinces are affected more than those coming from "dirty" provinces, which might be due to their different degrees of adaptation capacity and preferences for a clean environment. We also find that students that graduated from environmental schools care more about the air quality of their work destination, which may because they have more knowledge of the harm of air pollution. Finally, rising information transparency thanks to the internet and modern media amplifies the impacts of air pollution on the job location choice of top talent.

We acknowledge our constraint that we only have data from one university (Tsinghua University), which will lead to possible selection bias. We are unable to conduct Heckman selection bias control because we don't have data from other universities. Actually, since all elite universities need to enroll students through the standard national college entrance examination, student quality does vary significantly among top elite universities. Within a university such as Tsinghua, we do observe some variation of students' characteristics (gender, quality, etc.) between different schools with different majors. Therefore, we include major fixed effects in our main specification, and also conduct heterogeneous analysis for student groups, and find the results are robust.

The findings of this paper have important policy implications. On one hand, nowadays many cities both in developed and developing countries are rushing to propose programs to attract top talent, aiming to attract high human capital through higher incomes and better welfare. However, the demand for environmental quality and other urban amenities cannot be ignored. In the long term, improving environmental quality will be more effective for the high-quality urban growth driven by human capital. On the other hand, studies have found that land values increase in value when environmental quality improves (Zheng et al., 2010; Zheng et al., 2014). As demonstrated in this paper, the quantitative evidences of air quality's role in attracting talent and thus improving cities' competitiveness can help local governments effectively evaluate the social benefit of environmental regulation policies.

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Appendix:

Appendix Table 1. Heterogeneous effects between different students - IV estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Males	Females	Polluted hometown	Clean hometown	Environmental school	Other schools	Engineering	Art	Science
Panel A: All graduates									
pm	-0.0596**	-0.0470	-0.0304	-0.0865**	-0.0954	-0.0509**	-0.0674**	-0.0455	-0.0000464
	(0.0272)	(0.0288)	(0.0248)	(0.0345)	(0.0742)	(0.0253)	(0.0291)	(0.0323)	(0.0529)
share_lag	0.359***	0.459***	0.0136	0.418***	0.143***	0.394***	0.490***	0.0435	0.323***
	(0.0515)	(0.0507)	(0.0539)	(0.0533)	(0.0511)	(0.0515)	(0.0507)	(0.0551)	(0.0511)
N	419	419	419	419	419	419	419	419	419
R^2	0.412	0.463	0.143	0.438	0.262	0.429	0.481	0.158	0.307
Panel B: Undergraduates									
pm	0.0475	0.00923	0.0624	0.0678	0.0940	0.0357	0.0484	-0.000991	0.229**
	(0.0465)	(0.0562)	(0.0458)	(0.0583)	(0.168)	(0.0415)	(0.0560)	(0.0470)	(0.117)
share_lag	0.303***	0.0623	0.110**	0.258***	-0.413***	0.296***	0.360***	0.0192	-0.147***
	(0.0608)	(0.0575)	(0.0558)	(0.0614)	(0.0500)	(0.0615)	(0.0615)	(0.0552)	(0.0561)
N	419	419	419	419	419	419	419	419	419
R^2	0.148	0.060	0.044	0.205	0.187	0.120	0.117	0.076	0.084
Panel C: Graduates									
pm	-0.0785**	-0.0607*	-0.0425	-0.105**	-0.108	-0.0674**	-0.0833**	-0.0616*	-0.0174
	(0.0340)	(0.0323)	(0.0260)	(0.0416)	(0.0751)	(0.0306)	(0.0346)	(0.0360)	(0.0555)
share_lag	0.388***	0.479***	0.146***	0.464***	0.269***	0.418***	0.536***	-0.0109	0.429***
	(0.0511)	(0.0531)	(0.0542)	(0.0523)	(0.0509)	(0.0519)	(0.0500)	(0.0561)	(0.0481)
N	419	419	419	419	419	419	419	419	419
R^2	0.482	0.478	0.278	0.510	0.343	0.492	0.550	0.169	0.485

Note: (1) Control variables include city attributes, weather attributes, city fixed effects, and year fixed effects. (2) Heteroscedasticity-robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.