Research Article

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The Heterogeneous Effect and Transmission Paths of Air Pollution on Housing Prices: Evidence from 30 Large- and Medium-Sized Cities in China

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Abstract: Utilizing panel data from 30 large- and medium-sized cities in China from 2003 to 2018, this study employs the bootstrap method to investigate the heterogeneous impact of air pollution on housing prices and its underlying mechanisms. The research findings indicate that an increase in the concentration of various air pollutants has a restraining effect on housing prices, with the primary components of haze exerting a greater influence. Air pollution indirectly affects housing prices by influencing urban economic development and the development of the tertiary industry, with population density and the development of the secondary industry not serving as mediators in this relationship. Finally, policy recommendations are provided, including enhancing mandatory standards for energy consumption and waste gas emissions by enterprises, establishing a robust environmental monitoring system, and promoting industrial transformation and upgrading, aiming to provide insights for the stable development of the real estate industry.

Keywords: air pollution, housing prices, heterogeneity effect, transmission paths mediating effects

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1 Introduction

In the twenty-first century, with rapid economic development and continuous urbanization, the ecological environment in China has deteriorated, particularly in economically developed regions. In 2013, China experienced a severe haze problem, with peak concentrations of PM_{10} and $PM_{2.5}$ (as shown in Figure 1). The current state of air pollution has garnered widespread attention. A joint research report released in 2012 by the Asian Development Bank and Tsinghua University revealed that seven of the ten most polluted cities in the world were located in China. Furthermore, the air quality in Chinese cities significantly deviated from the standards set by the World Health Organization, with less than 1% of cities meeting these standards (Zhang & Crook, 2012). Since then, China's central and local governments have introduced numerous environmental protection and energy-saving policies to improve the air pollution situation. The scope of environmental monitoring has also expanded to include various prefecture-level cities. While under effective policy guidance, people and economic entities have become more aware of environmental protection and the air pollution problem has gradually eased, the concentrations of various air pollutants remain high, and Chinese cities still face severe environmental challenges. Data from the 2022 Report on the State of China's Ecological Environment revealed that out of 339 cities at the prefecture level or above, only 213 cities achieved the standard for environmental air quality, representing a compliance rate of 62.8% (Ministry of Ecology and Environment of China, 2023).

Air pollution not only has a significant impact on human health and the environment but also has significant effects on various sectors of the economy, including the real estate market. The real estate market plays a crucial role in the Chinese economy, serving as a vital source of household wealth accumulation and a major driver of economic activities. Despite scholars having extensively analyzed the heterogeneous impacts of deteriorating air quality on the real

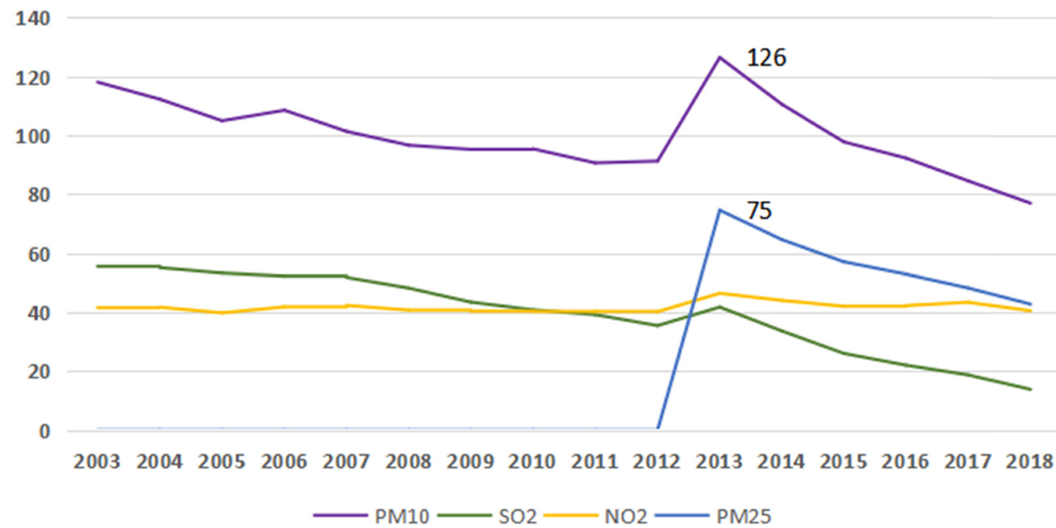

Figure 1: Concentration of each air pollutant (unit: μg/m^3).

estate market, there remains a considerable research gap regarding the specific mechanisms behind these impacts and the various factors contributing to this heterogeneity. As is the case in China, the impact of air pollution on the real estate market is complex and diverse due to the unique economic and environmental contexts of developing countries. This article examines the impact of different air pollutants on housing prices and analyses the mechanisms through which air pollution affects housing prices. This study not only contributes to enriching the theoretical understanding of the relationship between air pollution and housing prices but also provides policy support for air pollution control and housing price regulation.

The innovation of this article lies in its research perspective. First, based on the theory of revealed preferences, this study investigates the heterogeneous impacts of various air pollutants on urban housing prices from the perspectives of residents' housing purchase decisions and economic development. Second, by delving into the heterogeneous impact pathways of air pollution on housing prices, it is proposed that air quality can directly or indirectly affect socio-economic variables such as urban economic development and the level of development of the tertiary industry, which in turn affect urban housing prices. It also estimates the long-term impact of air pollution on housing prices, thereby enabling more targeted pollution control measures. In terms of research methodology, this article utilizes the hedonic price model to categorize air pollutants into industrial pollution and haze and employs a unified approach to comparatively analyze their impact on housing prices, which contributes to further exploring residents' sensitivity to various types of air pollution.

2 Literature Review

Existing research predominantly examines the causes of housing price fluctuations from the perspectives of resident income and consumption behavior, economic development level, and policy factors. However, with the increasing demands of residents for housing, investigating the impact of housing externalities on housing prices holds significance for society. Incorporating urban environmental factors into investment decisions is crucial for the sustainable development of the real estate market (Fu et al., 2023). Air pollution, as a characteristic of urban environments, can not only be an important reference indicator for housing location decisions but also, to some extent, a determinant of urban housing prices. According to the hypothesis of preference theory, people tend to settle and work in places with beautiful natural environments and avoid cities with severe air pollution. In addition to preference theory, the theoretical basis for the impact of air pollution on housing prices also stems from the theory of urban spatial equilibrium, namely, the differences in residential environments between cities can be reflected in housing prices (Zhou & Wang, 2018). In the interest of continuously improving urban residents' quality of life, air quality, as a feature of housing externalities, has gradually received increasing attention from the academic community. Currently, scholars mainly focus on two aspects.

First, scholars have mainly used the hedonic pricing model to analyze the direct effects of air pollution on housing prices, and most researchers have concluded that air pollution has a negative impact on housing prices. For example, Ridker and Henning (1967) found that a decrease in air pollution concentration would lead to an increase in housing prices in the St. Louis metropolitan area. Yusuf and Resosudarmo (2006) concluded that air pollution in Jakarta was negatively correlated with housing prices. However, Boennec and Salladarré (2017) found no causal relationship between air pollution and local housing prices in Nantes, France. Wang et al. (2019) found that air pollution in China indeed has a negative impact on housing prices, and this impact exhibits regional variations. Specifically, residents in eastern China are more sensitive to air pollution than those in other regions. Chen et al. (2018) estimated urban residents' marginal willingness to pay (WTP) for clean air utilizing the hedonic pricing method. Apart from confirming the adverse effect of air pollution on housing prices, their study also sheds light on the differential WTP for air quality improvement among various income groups.

Second, scholars have used econometric analysis methods to analyze the heterogenous effects of air pollution on housing prices and explored its internal mechanism. Using geographically weighted regression, Zou (2019) found that air pollution indeed has a negative impact on housing prices, with regional variations observed. Specifically, in China, the sensitivity of northern cities to air pollution is greater in the southeastern region. Wang et al. (2022) found that air pollution in large cities in China was significantly positively correlated with local housing prices, while air pollution in small- and medium-sized cities was negatively correlated with local housing prices. In addition, air pollution has a significant negative impact on housing prices in the western region, while it has no significant impact on housing prices in the eastern and central regions of China. Chen et al. (2018) estimated urban residents' marginal WTP for urban clean air, which not only confirmed the negative impact of air pollution on housing prices but also further demonstrated that different income groups have significant differences in their WTP for air quality improvement. Zhang et al. (2021) applied the spatial Durbin model to analyze spatial heterogeneity and concluded that within a range of 100 kilometers, when the total amount of air pollutants in neighboring cities doubled, local housing prices decreased by 6%. In this process, the city's geographical location and governance policies play a moderating role. Dong et al. (2020) analyzed the mechanism by which air pollution inhibits housing prices and found that the greater the level of urban economic development is, the greater the negative impact of air pollution on housing prices. In addition, scholars have conducted heterogeneous analyses on the impact of air pollution on housing prices in different periods and regions. The results show that during economic downturns, if government authorities strengthen macroeconomic regulation, then the suppressant impact of air pollution on housing price increases will become relatively limited [15]. This research contributes $t \times o$ further analyzing the heterogeneous effects of air pollution on housing prices in time and space, and the related findings also provide insights into exploring the impact pathways of air pollution on housing prices on a regional level.

As mentioned above, from the perspective of research content, scholars have focused on the magnitude and regional heterogeneity of the impact of air pollution on housing prices. However, few studies have investigated how air pollution affects housing prices. Although Liu et al. (2022) proposed that poor air quality negatively affects housing prices through channels such as hindering human capital, slowing down urbanization processes, and reducing people's housing price expectations, the research primarily analyzes $PM_{2.5}$ or industrial exhaust gases as explanatory variables without comparing the different effects of various air pollutants on housing prices, resulting in limited findings. More importantly, research on the impact of air pollution on housing prices through four potential channels – the urban population status, economic development level, industrialization degree, and construction level of public service facilities – has not received sufficient attention. To fill this gap in the literature, this article, based on the revealed preference theory, studies the heterogeneous effects of various air pollutants on urban housing prices from the perspective of residents' housing purchase decisions and economic development. Next, using the hedonic pricing model, air pollutants are divided into industrial pollution and haze, and a unified method is used to compare and analyze their impact on housing prices, which helps further explore residents' sensitivity to various types of air pollution. In addition, a quantitative comparative analysis is conducted on the influencing paths, and the authors propose that air quality can directly or indirectly affect socioeconomic variables such as urban economic development and the level of tertiary industry development (thereby affecting urban housing prices) and estimate the long-term impact of air pollution on housing prices, thereby enabling pollution control actions to be more effective.

From the perspective of research methodology, a challenge with traditional cross-sectional hedonic pricing models is the omission of variables. To address this problem, this study employs an improved hedonic pricing model to determine the long-term effects within a panel data framework. As suggested by Massetti and Mendelsohn (2011), the issue of omitted variables can be significantly reduced within a panel framework with fixed effects. Additionally, we test the sensitivity of our findings to alternative explanatory variables by incorporating various control variables and uncovering comparable results.

3 Research Hypothesis

3.1 Overall and Heterogeneous Impact of Air Pollution on Housing Prices

As a public resource, air quality has a direct impact on quality of life. Previous studies have shown that atmospheric pollutants can cause severe, irreversible damage to human physical and mental health that cannot be compensated by improvements in other conditions (Liu & Li, 2021). Severe air pollution greatly inconveniences residents in their daily lives and social interactions, leading people to reduce outdoor activities. Improving quality of life will increase demand for housing features and place more emphasis on the environmental quality of the cities in which they choose to live. Since 2013, China has gradually made air quality information about various cities available to the public, and the corresponding indicators have become important factors in assessing urban environmental quality. At the same time, urban residents have increasingly diverse channels to access information and can obtain real-time urban air pollution data through the Internet, mobile applications, and other means, further increasing their sensitivity to changes in pollution concentrations. Therefore, when making housing location decisions, consumer groups will gradually pay more attention to the current state of urban air pollution. Additionally, air pollution reduces urban vitality, restricts enterprise development, and affects the level of economic development, thus exerting a negative impact on urban housing prices.

The severity of the air quality situation in urban areas has sparked lively discussions in the academic community, and many scholars have analyzed fluctuations in housing prices in relation to the current state of air pollution in China. In terms of industrial pollutants, fossil fuels generally contain impurities such as sulfur and nitrogen, which produce pollutants such as SO_2 and NO_2 during combustion. Currently, China's energy consumption structure is still predominantly coal, its consumption is high in most industrial sectors. In cities with serious industrial pollution, industrial areas are also more concentrated. Although this can boost economic output, it is not conducive to improving urban livability, thus reducing the attractiveness of housing in these areas. The greater the emission intensity of industrial SO_2 and NO_2 is, the stronger their negative impact on housing prices (Li et al., 2020). Moreover, winter heating policies mainly rely on the burning of coal, natural gas, and other resources, which also results in air pollution problems. Since atmospheric pollution is harmful to physical and mental health, people generally do not prefer to settle in cities with severe industrial pollution. However, while SO_2 is one of the main atmospheric pollutants, its concentration is relatively low, and with the introduction of deindustrialization plans in some cities, residents have relatively low sensitivity to changes in this pollutant. Both NO_2 and SO_2 are industrial pollutants, so they are expected to have similar impacts on housing prices. Second, in recent years, haze has gained greater attention. Compared to industrial pollutants, particulate pollutants pose a greater threat to human health as they come from a wider range of sources and exist in higher concentrations. Government authorities find it difficult to formulate precise policies to address haze problems; thus, urban residents pay more attention to the primary pollutants that cause haze. An increase in PM_{10} and $PM_{2.5}$ concentrations in the atmosphere reduces urban vitality and residents' willingness to purchase homes, thus exerting a restraining effect on housing price increases. Since the gradual disclosure of atmospheric pollutant information in 2013, PM_{10} and $PM_{2.5}$ information has become more comprehensive and gained wider public awareness. Therefore, the public availability of air quality indicators will strengthen the negative impact of air pollution on housing prices. Since PM_{10} and $PM_{2.5}$ are similar pollutants, differing only in particle size, their overall impact on housing prices will tend to align. Therefore, this study proposes Hypothesis 1:

Hypothesis 1. Increases in the concentrations of PM_{10}, SO_2, NO_2, and $PM_{2.5}$ will have a negative impact on urban housing prices, but their levels of influence differ. The impact of industrial pollutants SO_2 and NO_2 will be relatively smaller, while the impact of haze components PM_{10} and $PM_{2.5}$ will be greater.

3.2 Transmission Paths through which Air Pollution Impacts Housing Prices

According to Tiebout's "voting with their feet" hypothesis, residents, given a sufficient budget, prefer to settle in cities that can meet their needs for physical and mental health as well as seek better living conditions. In recent years, awareness of environmental protection and health, especially regarding urban air pollution, has continued to increase. As air pollution has been proven to have serious detrimental effects on physical and mental health, people are more inclined to migrate to cities with good air quality. Some studies have also confirmed that the labor force is a major driving force behind population mobility. Considering job substitutability, highly skilled labor is more sensitive to air pollution (Sun et al., 2019) and more inclined to move to cities with clean air for employment, resulting in population migration driven by employment. Scholars have also confirmed that population mobility among prefecture-level cities is an important factor influencing housing prices in relation to air pollution (Chen et al., 2018). Additionally, with increasing public attention to urban air pollution and the promotion of green lifestyles, urban residents' sensitivity to air pollution will also increase. In other words, the more severe the air pollution problem in a city is, the more likely it is that human capital will be lost, and residents' willingness to migrate away will increase, which will affect the local population density. Based on this, we propose Hypothesis 2(a):

Hypothesis 2(a). Increases in the concentration of urban air pollutants will lead to a decrease in local population density, which will alleviate the phenomenon of housing supply–demand imbalance and indirectly restrain housing price increases.

The level of economic development is an important indicator of a city's vitality and a primary decision-making factor when people choose where to live. However, air pollution has a significant negative impact on the level of urban economic development (Chen & Chen, 2018). The Ministry of Ecology and Environment of China released the "Report on China's Economic-Ecological Production and Development" in 2018, which disclosed the gross economic-ecological product (GEEP) of each province and municipality in 2015. The provinces and municipalities with the highest GEEP were economically underdeveloped regions such as Tibet and Qinghai. However, regions with higher economic levels actually suffered significant ecological environment loss costs, with Hebei and Shandong ranking the highest. In 2015, the total Chinese gross domestic product (GDP) was 72.3 trillion yuan, with pollution loss costs as high as 2 trillion yuan, reflecting the adverse impact of environmental pollution on urban economic development. With the disclosure of smog-related information, air pollution has become an urgent issue that needs to be addressed. Studies have shown that the economic costs of outdoor air pollution will continue to increase, even reaching 1% of the global GDP, with China having the highest proportion of GDP loss (Elisa et al., 2018). Unregulated emissions of air pollutants not only reduce the attractiveness of cities and limit local industrial development but also disrupt the accumulation of human capital, thereby restraining economic development. Severe air pollution in cities will also have a corresponding impact on corporate investment willingness, leading to a decrease in the value of commercial real estate. Regardless of the perspective, air pollution will have a negative impact on the level of local economic development.

As a pillar of the national economy, the real estate sector exhibits a growth trend similar to that of GDP, as indicated by the close correlation between real estate development and economic growth. Theoretically, as the economic development of a city increases, the average income of local residents will correspondingly increase, leading to increased consumption capacity. An increase in the purchasing power of residents, who are the main consumers of housing, directly promotes an increase in housing prices. Therefore, an increase in the per capita GDP of a city will contribute to an increase in housing prices. Additionally, urban economic growth facilitates local industrial development and improvements in public infrastructure and subsequently increases the value of housing, exerting a positive influence on housing prices. Therefore, this study proposes Hypothesis 2(b):

Hypothesis 2(b). An increase in air pollution concentration will hinder urban economic development, and a decrease in economic level implies a decrease in residents' purchasing power, indirectly restraining housing price increases.

Urbanization in China significantly reflects the level of industrialization. In recent years, rapid urbanization in China has driven a series of industrial developments, mainly in the secondary and tertiary sectors. The secondary sector primarily includes the industrial and construction sectors. Although its rapid development has improved urban economic conditions, it has also led to more severe air pollution. Industrial production generates pollutants such as SO_2, NO_2, and particulate matter. The construction sector is also one of the main culprits of smog, as construction dust increases the concentration of particulate pollutants. Furthermore, activities such as heating and cooling contribute to an increase in pollutant concentrations, such as SO_2 and $PM_{2.5}$. Therefore, the secondary sector is the main source of urban air pollutants, meaning that cities with a higher degree of industrialization tend to have higher concentrations of air pollutants. Conversely, air pollution can also reflect the local level of industrialization to some extent. Cities with more severe air pollution are likely to have higher levels of economic development and industrialization, creating a "vicious cycle" (Wang & Cheng, 2021). Therefore, with the introduction of the carbon peak and carbon neutrality goals, China has paid great attention to the pollution emissions from high-polluting industries and power generation enterprises. Under a series of governance policies, an increase in urban air pollutant concentrations will restrict the development of the secondary sector. For instance, the public sector has formulated SO_2 emission limits and imposes carbon taxation policies, which will reduce the proportion of thermal power generation. In the post-industrial era, some cities may experience a trend of deindustrialization, which is unfavorable for local industrial development. Therefore, the development of the secondary sector is closely related to the current state of urban air pollution. Under a series of stringent control measures, such as emission limits and price controls, an increase in air pollutant concentrations will have a negative impact on the development of the urban secondary sector.

In recent years, there has been a growing interest in living a healthy lifestyle, with a preference for living in cities with excellent air quality. Although the accelerated process of industrialization implies economic development, the increase in the proportion of the secondary sector in cities often brings about more severe air pollution issues, affecting the quality of life for urban residents. Therefore, as some cities reach a saturation point in their level of industrialization, the severity of air pollution issues becomes increasingly acute, leading more people to be unwilling to settle in industrialized areas, which is then reflected in a negative impact on housing prices. Therefore, Hypothesis 2(c) is proposed:

Hypothesis 2(c). An increase in air pollution concentration will inhibit the development of the urban secondary sector, and a decrease in the proportion of the secondary sector will have a positive impact on the increase in local housing prices, reflecting an intermediary effect.

Modernization, which involves developing the tertiary sector and fostering technological advancements, is another component of urbanization in China. The tertiary sector primarily includes industries, such as services and commerce, and represents the level of urban public service facilities. With rising living standards, urban residents generally pay more attention to the provision of public services and prefer to settle in cities with a strong economy and well-resourced medical and education systems. The level of public service supply affects residents' quality of life, thereby influencing their decision on where to live. Moreover, cities with greater economic development tend to have more robust public services, which attracts people to move there. Consequently, the housing supply is outpaced by demand, leading to steadily rising housing prices. Therefore, policies aimed at improving quality of life will result in an increase in the proportion of the tertiary sector, which then attracts more human capital, resulting in rising housing prices. On the other hand, air pollution reduces urban vitality, diminishes human capital, and negatively affects a city's level of economic development. This also has certain negative impacts on the provision of local public services. Furthermore, severe pollution restricts residents' ability to enjoy outdoor activities, lowers the utilization rate of certain public infrastructure, affects local businesses' investments in public services, reduces demand for commercial real estate, and consequently leads to a decline in housing prices. Additionally, severe air pollution increases the government's cost of governance, reduces the willingness to invest in fixed assets, and redirects investments toward environmental protection. Based on these observations, this study proposes Hypothesis 2(d):

Hypothesis 2(d). An increase in air pollution concentration will inhibit the development of the tertiary sector, and a decrease in the proportion of the tertiary sector will indirectly lower the price level of local housing.

Based on the research hypotheses mentioned above, the potential impact path of air pollution on housing prices is illustrated in Figure 2. This study will quantitatively analyze four mediating paths: population density, level of economic development, proportion of the secondary sector, and proportion of the tertiary sector.

4 Variable Selection and Model Construction

4.1 Data Sources

The aim of this study is to investigate the impact of air pollution on housing prices in large- and medium-sized cities covering the period from 2003 to 2018. Since the National Bureau of Statistics only discloses air pollution data for 31 key environmental cities in their statistical yearbooks, this study selects these 31 large- and medium-sized cities as the research objects. Due to the relatively unique economic development of Lhasa City and the missing data in certain years, considering the data integrity and continuity, Lhasa City was excluded from the dataset. Therefore, the analysis is conducted on the data of the remaining 30 large- and medium-sized cities (as shown in Table 1). Based on the timing of the National Bureau of Statistics' information disclosure on $PM_{2.5}$, the study period is divided into two parts: the first part includes long-term data from 2003 to 2018, and the second part includes short-term data from 2013 to 2018. To obtain available data, reasonable control variables are selected to explore the effects of various air pollutant concentrations on housing prices. The focus of the analysis is primarily on the regression results of the

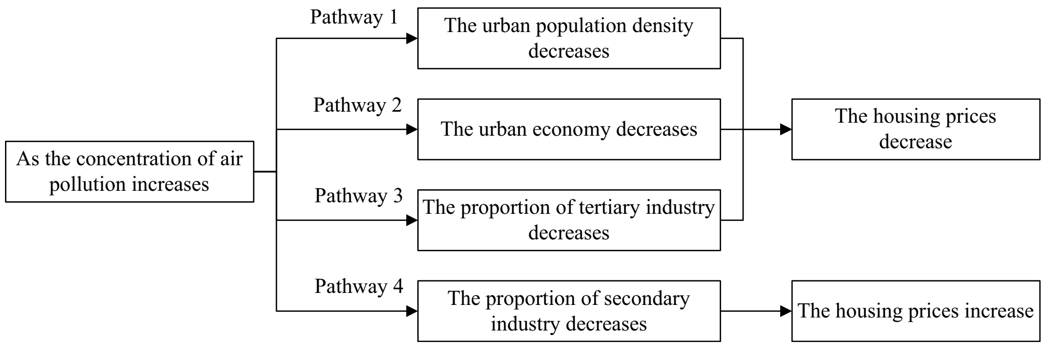

Figure 2: The influence paths of air pollution on housing prices.

long-term data. During the data compilation process, the original data range was from 2003 to 2019. However, due to the lack of data disclosure for some control variables in 2019, accurate data cannot be obtained in accordance with consistent standards. Therefore, the data for 2019 were excluded. The main sources of data for this study are the statistical yearbooks from 2004 to 2019. Housing price data are derived from the "China Real Estate Statistical Yearbook," air pollutant concentration data are sourced from the "China Statistical Yearbook," and control variable data mainly come from the "China Urban Statistical Yearbook." For certain missing data, references are made to provincial and municipal statistical yearbooks as well as national economic and social development statistical bulletins published by municipal governments.

4.2 Variable Selection

4.2.1 Independent and Dependent Variables

Considering the main sources and social hazards of air pollution, this study focuses on industrial pollution and haze as the primary objects of analysis. Four common air pollutant concentration indicators, namely, PM_{10}, SO_2, NO_2, and $PM_{2.5}$, are selected as independent variables. For the dependent variable, this study chooses the average selling price of commercial housing (HP). The descriptive statistics of each variable are presented in Table 2. SO_2 and NO_2 are industrial pollutants, while PM_{10} and $PM_{2.5}$ are both particulate matter pollutants. Since PM_{10} includes $PM_{2.5}$, and there are limited data available for $PM_{2.5}$ (2013 to 2018), the analysis is conducted from two dimensions: long-term and short-term. The long-term dimension includes the independent variables PM_{10}, SO_2, and NO_2, while the short-term dimension focuses on $PM_{2.5}$ as the independent variable.

4.2.2 Control Variables

Multiple factors influence housing prices. However, given that this study focuses on residential preferences and urban development as the research perspective, the analysis primarily examines the impact of air pollution on urban housing prices. Therefore, in selecting control variables, the emphasis is placed on choosing variables that describe the economic development of the city and the residents' purchasing power. Drawing on previous research, this study selects population density, per capita GDP, the proportion of GDP from the secondary and tertiary sectors, the number of doctors, the number of full-time teachers, and the number of books as control variables (Hong et al., 2020; Xiang & Li, 2019). The descriptive statistics of each variable are presented in Table 3.

Table 1: Classification of the 30 large- and medium-sized cities

Category	City
Northeast China	Harbin, Changchun, Jilin
Northern China	Beijing, Tianjin, Shijiazhuang, Taiyuan, Hohhot, Jinan
Central China	Wuhan, Changsha, Zhengzhou, Hefei, Nanchang
Western Region	Xi'an, Lanzhou, Xining, Yinchuan, Urumqi, Chengdu, Kunming, Nanning, Chongqing, Guiyang
Coastal cities	Guangzhou, Shanghai, Hangzhou, Fuzhou, Haikou, Nanjing

Table 2: Descriptive statistics for the independent and dependent variables

Variables	Definition	Observations	Average	Standard deviation	Minimum value	Maximum value
PM_{10}	Annual average concentration of respirable particulate matter (μg/m^3)	480	101.61	31.46	30.00	305.00
SO_2	Annual average sulfur dioxide concentration (μg/m^3)	480	40.53	23.28	5.00	152.00
NO_2	Annual average concentration of nitrogen dioxide (μg/m^3)	480	42.40	12.08	11.94	73.00
$PM_{2.5}$	Annual average concentration of fine particulate matter (μg/m^3)	180	57.78	21.19	18.00	154.00
HP	Average sales price of commercial properties (RMB/m^2)	480	6584.38	4597.64	1498.00	33820.00

The population of a city is closely related to the level of housing supply and demand. Therefore, population density is used to describe the population and reflect the housing demand situation. Per capita GDP serves as a measure of local economic development and, to some extent, reflects residents' living standards and purchasing power. The level of urbanization is measured by the industrial composition, with the proportion of the secondary sector indicating the level of industrial development and the proportion of the tertiary sector reflecting the development of the service industry. This analysis further explores the sensitivity of potential housing consumers to a city's industrial characteristics.

As urban residents' living standards continue to improve, the provision of public services has become an important external feature of housing and a significant factor influencing housing purchase intentions and price fluctuations. The number of doctors, the number of full-time teachers, and the total collection of books in public libraries are used to measure the medical and educational levels of different cities.

4.2.3 Selection of Mediating Variables

Based on the research hypotheses proposed, this study investigated four potential causal pathways and, therefore, selected four variables for the analysis of the mediating effects. Both air pollution and housing prices are closely related to a city's level of development. The level of public service provision can be used to measure a city's development potential, with higher levels indicating better local industrial development and livability. To avoid mutual interference and reverse causality issues among the pathways, this study includes the level of public services as a control variable when examining the mediating paths. In Pathway 1, the mediating variable is population density (Pop) to test Hypothesis 2(a). In Pathway 2, the mediating variable is per capita GDP (GDP_per) to test Hypothesis 2(b). In Pathway 3, the mediating variable is the proportion of GDP from the secondary sector (GDP_ratio2) to test Hypothesis 2(c). Finally, in Pathway 4, the mediating variable is the proportion of GDP from the tertiary sector (GDP_ratio3) to test Hypothesis 2(d).

To eliminate heteroscedasticity and enhance stability, this study first performs a logarithmic transformation on the data. Additionally, to eliminate the influence of price factors and improve the accuracy of the results, this study applies deflation to variables measured in monetary units. Referring to previous research, the consumer price index (CPI) for each city is calculated using 2003 as the base

Table 3: Descriptive statistics for control variables

Variables	Definition	Observations	Average	Standard deviation	Minimum value	Maximum value
GDP_per	Gross regional product (yuan/person)	480	65355.72	45999.29	3514.33	246329.20
GDP_ratio2	Share of secondary sector GDP (%)	480	43.35	8.39	18.14	60.13
GDP_ratio3	Share of tertiary sector GDP (%)	480	51.38	9.23	36.20	80.98
Doctor	Practitioner (including Assistant Practitioners) Number (persons)	480	22253.23	16144.03	2462.00	109376.00
Teacher	Number of full-time teachers (persons)	480	86986.85	51387.03	15337.00	305738.00
Book	Total Public Library Book Collection (million volumes)	480	1036.99	1426.57	31.00	7894.00
Pop	Population density (person/km^2)	480	620.94	412.35	123.95	2305.63

period, and this index is used to deflate various types of housing prices, GDP, and per capita GDP data. The descriptive statistics of the deflated variables are presented in Table 4.

4.3 Model Construction

4.3.1 Main Effect Model

(1) Long-term data:

$$\ln \mathrm{HP}_{it} = \beta_0 + \beta_k X_{kit} + \rho_j \ln C_{jit} + \varepsilon_{it}. \quad (1)$$

(2) Short-term data:

$$\ln \mathrm{HP}_{it} = \gamma_0 + \gamma_1 \ln \mathrm{PM}_{2.5it} + \rho_j \ln C_{jit} + \varepsilon_{it}. \quad (2)$$

The model is used to analyze the overall effect of air pollution on housing price levels and to explore the level of significance of each variable. In the above models, i denotes the city, t denotes time, and C_j ($j \in 1,2, \ldots,7$) are the control variables, denoted Pop, GDP_per, GDP_ratio2, GDP_ratio3, Doctor, Teacher, and Book. The term ε_{it} represents the residual terms. Model 1 focuses on the effect of each air pollutant on housing prices, with X_k being the logarithmic transformation of each explanatory variable and k = 1,2,3 representing PM_{10}, SO_2 and NO_2. Since there are some synergistic effects among the pollutants, this article substitutes PM_{10}, SO_2 and NO_2 for the analysis to avoid multicollinearity. Model 2 examines the effect of $PM_{2.5}$ on housing prices, as $PM_{2.5}$ is the main component of haze and is cross-sectioned with PM_{10} data; this regression includes only $PM_{2.5}$ as an explanatory variable.

4.3.2 Mediating Effects Model

This section examines the mediating effect of air pollution on housing prices. Taking the explanatory variable PM_{10} as an example, stepwise regression is first used to determine whether urban PM_{10} concentration indirectly causes fluctuations in housing prices by affecting four variables: population size, GDP per capita, share of secondary industry, and share of tertiary industry. Second, based on the stepwise regression, bootstrap tests are conducted for each influence path to quantify the mediating effect of air pollution on urban housing prices. The model for analyzing each impact path is shown below:

(1) Validation of Pathway 1: Whether PM_{10} concentrations indirectly affect housing prices by influencing urban population density:

$$\ln \mathrm{HP}_{it} = \alpha_1 + m_1 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it},\ j \in (5, 6, 7), \quad (3)$$

$$\ln \mathrm{Pop} = \sigma_1 + b_1 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it}, \quad (4)$$

$$\ln \mathrm{HP}_{it} = \alpha_1' + m_1' \mathrm{PM}_{10} + n_1 \ln \mathrm{Pop} + \rho_j' \ln C_{jit} + \varepsilon_{it}. \quad (5)$$

(2) Validation of Pathway 2: Whether PM_{10} concentration indirectly affects housing prices by affecting the GDP per capita:

$$\ln \mathrm{HP}_{it} = \alpha_2 + m_2 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it},\ j \in (5, 6, 7), \quad (6)$$

$$\ln \mathrm{GDP\_per} = \sigma_2 + b_2 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it}, \quad (7)$$

$$\ln \mathrm{HP}_{it} = \alpha_2' + m_2' \mathrm{PM}_{10} + n_2 \ln \mathrm{GDP\_per} + \rho_j' \ln C_{jit} + \varepsilon_{it}. \quad (8)$$

(3) Validation of Pathway 3: Whether PM_{10} concentration indirectly affects housing prices by influencing the share of the secondary sector:

$$\ln \mathrm{HP}_{it} = \alpha_3 + m_3 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it},\ j \in (5, 6, 7), \quad (9)$$

$$\ln \mathrm{GDP\_ratio2} = \sigma_3 + b_3 \mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it}, \quad (10)$$

Table 4: Descriptive statistics for the deflator variables

Variables	Definition	Observations	Average	Standard deviation	Minimum value	Maximum value
HP	Average sales price of commercial properties (RMB/m^2)	480	5148.39	3286.02	1498.00	24401.36
GDP	Gross regional product (billion yuan)	480	3119.91	3064.00	144.83	15783.74
GDP_per	Gross regional product (yuan/person)	480	53818.01	84172.04	1214.99	747272.50

$$\ln \mathrm{HP}_{it} = \alpha_3' + m_3'\mathrm{PM}_{10} + n_3 \ln \mathrm{GDP\_ratio2} + \rho_j' \ln C_{jit} + \varepsilon_{it}. \quad (11)$$

(4) Validation of Pathway 4: Whether PM_{10} concentration indirectly affects housing prices by influencing the share of the tertiary sector:

$$\ln \mathrm{HP}_{it} = \alpha_4 + m_4\mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it},\ j \in (5, 6, 7), \quad (12)$$

$$\ln \mathrm{GDP\_ratio3} = \sigma_4 + b_4\mathrm{PM}_{10} + \rho_j \ln C_{jit} + \varepsilon_{it}, \quad (13)$$

$$\ln \mathrm{HP}_{it} = \alpha_4' + m_4'\mathrm{PM}_{10} + n_4 \ln \mathrm{GDP\_ratio3} + \rho_j' \ln C_{jit} + \varepsilon_{it}. \quad (14)$$

5 Empirical Analysis

5.1 Data Stability Test

5.1.1 Unit Root Test

To ensure the accuracy of the results and avoid spurious regression, this study initially tested the presence of a unit root in the time series of each variable. However, separate unit root tests were not conducted for the $PM_{2.5}$ variable due to its short time series, which spanned only six years and lacked clear regularity. Instead, the LLC, IPS, ADF, and PP tests were conducted for the other long-term variables individually. Considering the large values of the data, the variables were logarithmically transformed. The null hypothesis (H_0) was that the panel data contained unit roots. The results of the unit root tests indicated that some of the variables in the original series did not pass the test, suggesting that these variables are not stable over time. The specific test results are presented in Table 5.

Since some of the data in the original series did not pass the unit root test, first-order differencing was performed on each data series, and the unit root test was reconducted. The results indicated that the first-order differenced series exhibited stationarity. The specific test results are presented in Table 6.

5.1.2 Co-Integration Test

Although first-order differencing can yield stationary series for variables with unit roots, it is important to note that in

Table 5: Unit root test results for the original series data

Variables	LLC	IPS	ADF	PP
$\ln \mathrm{HP}$	−6.103***	−5.519***	89.052***	110.290***
$\ln \mathrm{PM}_{10}$	−6.337***	−5.732***	89.115***	89.673***
$\ln \mathrm{SO}_2$	−0.925	−3.358***	145.217***	78.556*
$\ln \mathrm{NO}_2$	−5.334***	−5.124***	143.613***	96.485***
$\ln \mathrm{Pop}$	−4.466***	−5.862***	82.008**	141.538***
$\ln \mathrm{GDP\_per}$	−7.762***	−3.633***	136.306***	93.040***
$\ln \mathrm{GDP\_ratio2}$	−5.097***	−0.797	102.833***	82.671**
$\ln \mathrm{GDP\_ratio3}$	−2.957***	0.189	167.261***	95.534***
$\ln \mathrm{Doctor}$	−5.623***	−6.116***	112.066***	142.434***
$\ln \mathrm{Teacher}$	−4.494***	−5.374***	122.571***	146.508***
$\ln \mathrm{Book}$	−6.581***	−6.427***	113.581***	127.224***

Note: *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 6: Unit root test results for first-order difference data

Variables	LLC	IPS	ADF	PP
$\ln \mathrm{HP}$	−7.147***	−10.058***	105.027***	372.170***
$\ln \mathrm{PM}_{10}$	−10.772***	−10.659***	89.070***	320.149***
$\ln \mathrm{SO}_2$	−5.634***	−8.655***	124.360***	311.678***
$\ln \mathrm{NO}_2$	−13.173***	−10.404***	110.754***	429.073***
$\ln \mathrm{Pop}$	−7.993***	−11.003***	128.971***	356.088***
$\ln \mathrm{GDP\_per}$	−8.289***	−10.448***	101.190***	283.955***
$\ln \mathrm{GDP\_ratio2}$	−8.012***	−8.746***	94.328***	280.264***
$\ln \mathrm{GDP\_ratio3}$	−9.834***	−9.348***	138.046***	310.964***
$\ln \mathrm{Doctor}$	−13.304***	−11.100***	134.451***	560.737***
$\ln \mathrm{Teacher}$	−8.826***	−10.700***	113.154***	437.427***
$\ln \mathrm{Book}$	−9.888***	−10.968***	121.792***	417.070***

Note: *** indicate significance at the 1% levels.

general, first-order differencing may affect the interpretation of variables and introduce differences in economic meaning compared to the original series. Therefore, in regression analysis, it is desirable to use the original series data. To address this issue, this study conducted cointegration tests using the Kao test based on the Engle–Granger two-step method. The analysis revealed that all the data used in the model passed the cointegration test, indicating the presence of a long-term stable relationship among the variables, thus enabling empirical analysis. The results of the cointegration test are presented in Table 7.

5.2 Impact of Air Pollution on Urban Housing Prices

While urbanization stimulates economic growth, it also facilitates industrial agglomeration and, to some extent, gives rise to urban air pollution issues [21], indicating an endogenous influence. To address endogeneity concerns, this study employs lagged one-period air pollution data in the regression analysis when dealing with long-term data and includes control variables by dimension. Additionally, the F test and Hausman test are applied to select the appropriate model, ensuring the accuracy of the regression results.

Table 7: Results of the Kao test for the basic model

		ADF	
Models		**Statistical quantities**	***P* value**
Model 1	(1) $\ln PM_{10}$	-3.4689^{***}	0.0003
	(2) $\ln SO_2$	-4.0711^{***}	0.0000
	(3) $\ln NO_2$	-3.6858^{***}	0.0001
Model 2	(1) $\ln HP$	-1.8268^{**}	0.0339
	(2) $\ln BS$	-2.9560^{***}	0.0016
	(3) $\ln RD$	-6.2373^{***}	0.0000
Model 3			
$\ln Pop$	Model 1	-3.3967^{***}	0.0003
	Model 2	-2.7464^{***}	0.0030
	Model 3	-3.4551^{***}	0.0003
$\ln GDP\_per$	Model 2	-3.8408^{***}	0.0001
	Model 3	-2.7341^{***}	0.0031
$\ln GDP\_ratio\ 2$	Model 2	-3.0914^{***}	0.0010
	Model 3	-4.2853^{***}	0.0000
$\ln GDP\_ratio\ 3$	Model 2	-3.5823^{***}	0.0002
	Model 3	-4.4111^{***}	0.0000

Note: ** and *** indicate significance at the 5 and 1% levels, respectively.

5.2.1 PM_{10} Impact on Urban House Prices

The model results indicate a significant negative effect of PM_{10} concentration on housing prices, which is consistent with the research hypothesis that higher PM_{10} concentrations in cities have a substantial negative impact on housing prices. As the control variables that describe other city characteristics are included, the negative effect of PM_{10} on housing prices gradually diminishes. The regression results are shown in Table 8.

First, in Column (1), this study directly analyzes the independent impact of PM_{10} on housing prices and finds that a 10% increase in PM_{10} concentration leads to a 7.18% decrease in local housing prices. This suggests that higher PM_{10} concentrations significantly hamper the development of the local real estate industry. Building upon this, in column (2), the study incorporates the population density variable for analysis, and the negative effect of PM_{10} on housing prices diminishes, indicating a close relationship between the negative impact of PM_{10} on housing prices and city characteristics. At the same time, population density has a positive effect on housing prices, reflecting the effect of population agglomeration. In other words, the greater the population density in a city, the faster the increase in housing prices. Due to limited land supply, population growth further intensifies housing demand, leading to a scarcity of land resources and subsequent price increases. This conclusion aligns with the findings of other researchers (Chen & Chen, 2017).

The provision of public services in a city affects the quality of life of its residents and may bring a premium to

Table 8: Effect of PM_{10} concentration on housing prices

Variables	**(1) ln HP**	**(2) ln HP**	**(3) ln HP**	**(4) ln HP**
$\ln PM_{10}$	-0.715^{***}	-0.687^{***}	-0.281^{***}	-0.155^{***}
$\ln Pop$		1.168^{***}	0.005^{***}	−0.027
$\ln Doctor$			0.553^{***}	0.209^{***}
$\ln Teacher$			0.916^{***}	0.481^{***}
$\ln Book$			0.013	−0.007
$\ln GDP\_per$				0.426^{***}
$\ln GDP\_ratio2$				−0.157
$\ln GDP\_ratio3$				0.644^{***}
Constant	11.729^{***}	4.311^{***}	-6.107^{***}	-4.479^{***}
Observations	450	450	450	450
R^2	0.14	0.24	0.75	0.83
F-statistic	22.52^{***}	17.38^{***}	33.45^{***}	39.37^{***}
Hausman test	4.38	25.87^{***}	118.51^{***}	75.85^{***}

Note: *** indicate significance at the 1% levels.

the property. Therefore, in column (3), this article adds control variables to reflect public services (number of doctors, number of teachers, and number of book collections) and finds that for PM_{10}, the negative effect of concentration on urban housing prices will be significantly reduced. The data suggest that when PM_{10}, the level of public services in the city significantly contributes to the increase in urban housing prices and can mitigate the negative impact of air pollution on the development of the urban real estate industry to a certain extent. In column (4), this article adds GDP per capita and industry share as control variables because GDP per capita and tertiary industry share have a facilitating effect on the increase in housing prices. In this case, the impact of PM_{10} concentration on urban housing prices is reduced to 1.55%. However, even if other positive characteristics of a city can help offset the negative effect of air pollution on housing prices, this does not change the fact that this negative effect is significant. In addition, and in contrast to the findings of existing studies, a rising share of urban secondary industries may have a negative effect on urban house price inflation, reflecting the fact that residents may increasingly prefer to live in less industrialized cities with more developed service industries.

5.2.2 The Impact of SO_2 and NO_2 on Urban Housing Prices

The model results show that SO_2 and NO_2 concentrations also have a negative impact on urban housing prices, but overall, this impact is not significant. This suggests that for urban residents, these two air pollutants may not be the primary factors influencing housing price expectations. First, the main source of these two air pollutants is industrial pollution, which is more related to industrial clustering and less relevant to residents' normal production activities. Second, compared to PM_{10}, the concentrations of SO_2 and NO_2 are relatively low. Therefore, when making location decisions, residents are more concerned about the primary components of haze, and they pay relatively less attention to industrial pollutants. The regression results are shown in Table 9.

First, we analyze the negative impact of SO_2 concentration on urban housing prices. Column (1) shows that when the SO_2 concentration increases by 10%, the local housing prices decrease by 4.48%, indicating that SO_2 hinders the increase in housing prices. After including the population density variable, the negative impact of SO_2 on housing prices decreases to some extent due to population agglomeration effects, but it remains significant. In column (3), after incorporating variables related to public services, the adverse effect of SO_2 on housing price increases is significantly reduced (1.02%), further highlighting the positive role of urban public services in housing price increases. However, it still cannot compensate for the expected devaluation caused by air pollution. In column (4), when other control variables are added, the decrease in housing prices is not significant when the SO_2 concentration increases, indicating that the urban SO_2 concentration does not significantly affect residents' expected housing prices. Similar to the regression results for PM_{10}, increases in ln GDP_per and ln GDP_ratio3 contribute to

Table 9: Effect of SO_2 and NO_2 concentrations on housing prices

Variables	SO_2				NO_2			
	(1) ln HP	(2) ln HP	(3) ln HP	(4) ln HP	(1) ln HP	(2) ln HP	(3) ln HP	(4) ln HP
$\ln SO_2/\ln NO_2$	-0.448^{***}	-0.415^{***}	-0.102^{***}	−0.014	0.303^{***}	0.244^{***}	-0.124^{**}	−0.434
ln Pop		0.612^{***}	−0.316	−0.028		1.330^{***}	−0.038	−0.028
ln Doctor			0.521^{***}	0.201^{***}			0.726^{***}	0.208^{***}
ln Teacher			0.868^{***}	0.480^{***}			0.250^{**}	0.499^{***}
ln Book			0.009	−0.008			0.031	−0.006
ln GDP_per				0.447^{***}				0.444^{***}
ln GDP_ratio2				−0.180				−0.166
ln GDP_ratio3				0.621^{***}				0.659^{***}
Constant	10.038^{***}	6.102^{***}	-5.922^{***}	-5.080^{***}	7.318^{***}	−0.752	-1.417^{**}	-5.468^{***}
Observations	450	450	450	450	450	450	450	450
R^2	0.40	0.43	0.74	0.83	0.09	0.12	0.73	0.83
F-statistic	30.33^{***}	21.91^{***}	24.60^{***}	30.66^{***}	16.49^{***}	12.84^{***}	38.84^{***}	44.79^{***}
Hausman Test	2.28	8.44^{**}	107.50^{***}	93.83^{***}	0.95	27.10^{***}	121.92^{***}	77.34^{***}

Note: ** and *** indicate significance at the 5 and 1% levels, respectively.

rising local housing prices. This phenomenon suggests that when urban features meet residents' expectations and air pollutant concentrations are relatively low, air pollution may not strongly negatively affect housing price increases.

Compared to the results for SO_2, the negative impact of NO_2 on housing prices is relatively low. The low R^2 values in columns (1) and (2) indicate a weak explanatory power of NO_2 on urban housing prices, and the estimated results may contain errors. Therefore, additional control variables need to be included. In column (3), after incorporating variables related to public services, the model fit is better, and at a significance level of 10%, a 10% increase in NO_2 concentration is associated with a 1.24% decrease in local housing prices, indicating a certain negative impact. However, when other control variables are added, similar to the SO_2 results, the negative impact of increasing NO_2 concentration on urban housing prices is not significant. These regression results indicate that increases in SO_2 and NO_2 concentrations may not be the main reasons hindering housing price increases.

5.2.3 $PM_{2.5}$ Impact on Urban House Prices

Due to limitations in data availability, the number of observations in this model is relatively small, which may introduce bias into the regression results. However, the research findings indicate a significant negative impact of $PM_{2.5}$ concentration, one of the main components of haze, on urban housing prices, consistent with the hypothesis of this study. The degree of influence of $PM_{2.5}$ concentration on urban housing prices is presented in Table 10.

Table 10: Effect of $PM_{2.5}$ concentration on housing prices

Variables	(1) ln HP	(2) ln HP	(3) ln HP	(4) ln HP
$\ln PM_{2.5}$	−0.498***	−0.531***	−0.339***	−0.319***
ln Pop		−0.133	−0.127	−0.109
ln Doctor			0.336***	0.294***
ln Teacher			0.203	0.126
ln Book			−0.049**	−0.053**
ln GDP_per				0.120
ln GDP_ratio2				−0.387
ln GDP_ratio3				−0.357
Constant	10.721***	11.685***	5.634**	8.332**
Observations	180	180	180	180
R^2	0.02	0.54	0.59	0.60
F-statistic	95.16***	57.49***	35.79***	27.50***
Hausman test	4.50	19.78***	19.93***	18.00**

Note: ** and *** indicate significance at the 5 and 1% levels, respectively.

First, the negative impact of $PM_{2.5}$ concentration on urban housing prices is evident, as shown in column (1). A 10% increase in $PM_{2.5}$ concentration leads to a decrease of 4.98% in local housing prices, indicating a significant effect. After introducing control variables such as population density and dimensions of public services in column (3), the negative impact of $PM_{2.5}$ concentration on urban housing prices decreases to 3.39%. This finding aligns with the regression results of PM_{10} and demonstrates the mitigating effect of improved urban public services on the influence of air pollution. However, the direction of the effect of population density on housing prices changes to negative, although it is not statistically significant. In column (4), when additional control variables are included, the negative impact coefficient of $PM_{2.5}$ on urban housing prices further decreases, but variables such as GDP per capita and industry ratio do not show a significant relationship with housing prices. The possible reasons for these results are the short data series, which may lack long-term stability, and the fact that population density only partially represents the level of population mobility in the city, leading to deviations in short-term regression. The low R^2 value also indicates room for improvement in data fitting. Nevertheless, the regression results of this model confirm that an increase in $PM_{2.5}$ concentration hinders the rise in urban housing prices, aligning with the findings of other scholars. Studies focusing on various prefecture-level cities commonly recognize a negative correlation between $PM_{2.5}$ and housing prices.

By comparing the differential impacts of various air pollutants on urban housing prices, it can be concluded that all air pollutants exhibit a negative correlation with housing prices, with PM_{10} and $PM_{2.5}$, the primary components of haze, having a greater influence. Hypothesis 1 is validated, as a 10% increase in PM_{10} and $PM_{2.5}$ concentrations leads to a decrease in housing prices of 1.55 and 3.19%, respectively. The negative impacts of increasing SO_2 and NO_2 concentrations on housing prices are not statistically significant. However, they may still cause a decline in expected housing prices. This suggests that residents pay less attention to industrial air pollution when making housing decisions but are more sensitive to changes in PM_{10} and $PM_{2.5}$ concentrations in the atmosphere.

5.2.4 Transmission Paths through Which Air Pollution Impacts Housing Prices

Based on the aforementioned analysis, this study conducts a mediation analysis using the PM_{10} variable, which has the most significant negative impact on housing prices, to verify the pathway through which air pollution affects urban housing prices. First, a stepwise regression method is employed to verify whether PM_{10} concentration influences population density, per capita GDP, and industrial composition. Second, this study examines whether PM_{10} indirectly affects housing prices by influencing these three aspects. Based on the research hypothesis, a total of four potential pathways need to be tested for mediation.

Table 11 shows that this study examines whether PM_{10} concentration indirectly affects housing prices by influencing the urban population density and economic development level. The nonsignificant regression results of PM_{10} on population density suggest that changes in urban population density may not be the main pathway through which PM_{10} concentration affects housing prices, indicating that Hypothesis 2(a) fails to pass the test. This result may be attributed to the relatively low proportion of the floating population in the total population of some cities, leading to biased analysis results. As a city with a relatively developed economy, Shanghai's net migration rate in 2016 was 4.56%, accounting for a relatively small proportion of the total population. In 2018, Urumqi had a negative net migration rate, which did not significantly affect the city's population density. Therefore, population mobility has a relatively greater impact on population density in prefecture-level cities. However, when focusing on provincial capital cities, although severe air pollution conditions may lead residents to consider outward migration, they also face significant migration costs, which reduce this influence. Analyzing the situation based on urban population mobility may yield different results.

The results of the Path 2 test indicate that an increase in PM_{10} concentration has a significant negative impact on urban per capita GDP. According to the regression results, both coefficients, $b_2 = -0.199$ and $n_2 = 0.453$, are significant, and the product of the coefficients, $b_2 \times n_2 = -0.09 < 0$, is negative. This result is consistent with = −0.191, suggesting the possible existence of a mediating effect, and Hypothesis 2(b) is validated. Additionally, according to the third column of the regression results, PM_{10} has a significant negative impact on urban housing prices. This mediating effect is partial, meaning that an increase in PM_{10} concentration directly affects housing prices and indirectly suppresses price increases by hindering the increase in per capita GDP.

In Path 3 of Table 12, this study verifies whether PM_{10} concentration indirectly affects housing price levels through its impact on the share of secondary industry in cities. The research results show that at a significance level of 5%, an increase in PM_{10} concentration has a certain positive impact on the share of secondary industry in cities. This finding differs from Hypothesis 2© of this study but aligns with the conclusions of other scholars. There are two main reasons why Hypothesis ©(c) did not pass. First, secondary industry still acts as a driving force for economic development, and an increase in air pollution concentration indicates a favorable environment for the development of secondary industry in the local area. In some cities, to achieve economic growth, local governments may have a less proactive approach to pollution control, resulting in a positive impact of air pollution on the increase in the share of secondary industry. Second, it is possible that the lagged variable method used in this study does not fully address the bidirectional causality between industrialization and air pollution. <>The improvement in the level of urban industrialization may have a reverse effect on the level of air pollution, causing bias in the regression results. Using instrumental variables such as the ventilation coefficient and pollution control policies can to some extent alleviate the reverse

Table 11: The mediating effects of PM_{10} concentration on housing prices

Variables	Path 1			Path 2		
	(1) ln HP	(2) ln Pop	(3) ln HP′	(1) ln HP	(2) ln GDP_per	(3) ln HP′
$\ln PM_{10}$	−0.281***	−0.008	−0.281***	−0.281***	−0.199***	−0.191***
ln Pop			0.004			
ln GDP_per						0.453***
ln Doctor	0.553***	0.030	0.553***	0.553***	0.499***	0.327***
ln Teacher	0.917***	0.264***	0.916***	0.917***	0.934***	0.495***
ln Book	0.012	0.026**	0.013	0.012	0.045*	−0.008
Constant	−6.092***	3.250***	−6.107***	−6.092***	−4.336***	−4.129***
Observations	450	450	450	450	450	450
R^2	0.75	0.20	0.75	0.75	0.71	0.80
F-statistic	36.50***	576.61***	33.45***	36.50***	196.53***	38.71***

Note: *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 12: Mediated effects of PM_{10} concentration on housing prices

Variables	Path 3			Path 4		
	(1) lnHP	(2) lnGDP_ratio2	(3) lnHP′	(1) lnHP	(2) lnGDP_ratio3	(3) lnHP′
$\ln PM_{10}$	−0.281***	0.063**	−0.246***	−0.281***	−0.050**	−0.234***
lnGDP_ratio2			−0.558***			0.950***
lnGDP_ratio3						
lnDoctor	0.553***	−0.170***	0.459***	0.553***	0.165***	0.397***
lnTeacher	0.917***	−0.046	0.892***	0.917***	0.061	0.860***
lnBook	0.012	0.000	0.012	0.012	−0.001	0.013
Constant	−6.092***	5.634***	−2.946***	−6.092***	1.866***	−7.865***
Observations	450	450	450	450	450	450
R^2	0.75	0.27	0.77	0.75	0.39	0.79
F-statistic	36.50***	47.94***	36.16***	36.50***	41.68***	34.26***

Note: ** and *** indicate significance at the 5 and 1% levels, respectively.

causality between the two. However, according to the regression results, $b_3 \times n_3 = -0.035 < 0$, which is consistent with $m_3' = -0.246$, indicating that the share of the secondary industry in cities may also be one of the pathways that affects housing prices. Since an increase in PM_{10} concentration directly affects housing prices, this mediating effect is also partial.

In Pathway 4, this study verifies whether an increase in PM_{10} concentration indirectly affects housing price levels through its impact on the share of tertiary industry in cities. The results show that an increase in PM_{10} concentration directly suppresses housing price increases, and the effect is significant ($m_4' = -0.234$). In the mediating path, an increase in PM_{10} concentration has a significant inhibitory effect on the development of the tertiary industry in cities ($b_4 = -0.050$), indicating that severe air pollution conditions are unfavorable for the development of the local service industry, thereby affecting the level of public services in cities. Furthermore, since $b_4 \times n_4 = -0.048 < 0$ and is consistent with $m_4' = -0.234$, an increase in PM_{10} concentration may indirectly affect local housing price levels by hindering the development of tertiary industry in cities, validating Hypothesis 2(d). This indirectly demonstrates the positive effect of improving the provision of urban public services on housing prices.

Due to the potential influence of the stepwise regression method on the significance of mediating effects, to further compare the magnitude of the pathways through which PM_{10} concentration affects housing prices, this study conducts bootstrap tests on each mediating path to illustrate their indirect effects. The test results are shown in Table 13. The indirect effect of Path 1 is zero, indicating that population density is not the pathway through which PM_{10} affects urban housing prices, which is consistent with the results of the stepwise regression method. The test results for Path 2 indicate that when the PM_{10} concentration increases by 10%, it directly leads to a 1.91% decrease in housing prices, indirectly causing a 0.9% decrease through the pathway of per capita GDP, and both direct and indirect effects are significant, indicating a partial mediating effect, with the mediation proportion being 32.03%.

Table 14 presents the pathway analysis of the industrial structure. The confidence interval of Path 3 includes zero, indicating that the mediating effect is not established. Therefore, it can be concluded that PM_{10} concentration

Table 13: Bootstrap test for impact paths

	Path 1			Path 2		
	Indirect effects	Direct effects	Total effect	Indirect effects	Direct effects	Total effect
Coefficient	−0.0000	−0.2810***	−0.2810***	−0.0900**	−0.1910***	−0.2810***
Statistical quantities	−0.0100	−4.8200***		−2.1500**	−3.2300***	
Confidence interval						
Lower limit	−0.0071	−0.3960		−0.1723	−0.3074	
Upper limit	0.0071	−0.1669		−0.0078	−0.0753	

Note: ** and *** indicate significance at the 5 and 1% levels, respectively.

Table 14: Bootstrap test for impact paths

	Pathway 3			Pathway 4		
	Indirect effects	**Direct effects**	**Total effect**	**Indirect effects**	**Direct effects**	**Total effect**
Coefficient	−0.0350*	−0.2460***	−0.2810***	−0.0480**	−0.2340***	−0.2820***
Statistical quantities	−1.7000*	−4.0000***		−1.9800**	−4.3600***	
Confidence interval						
Lower limit	−0.7571	−0.3670		−0.0951	−0.3387	
Upper limit	0.0053	−0.1256		−0.0003	−0.1288	

Note: *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

does not indirectly affect local housing price levels through its impact on the share of secondary industry. This finding may also be related to the reverse causality between urban industrialization and air pollution. In the test for Pathway 4, when the PM_{10} concentration increases by 10%, it directly leads to a 2.34% decrease in housing prices and indirectly causes a 0.48% decrease through its impact on the share of the tertiary industry. Both the direct and indirect effects are significant. This pathway also exhibits a partial mediating effect, with a mediation proportion of 17.21%.

In summary, this study analyzed the impact of PM_{10} concentration and found that it not only directly affects housing prices negatively but also has indirect effects through its influence on per capita GDP and the development of the tertiary industry. This confirms the existence of mediating effects and partially validates Hypotheses 2(b) and 2(d). However, Hypotheses 2(a) and 2(c) were not supported. In terms of the magnitude of the mediating effects, the indirect effect through per capita GDP is greater than that through the share of the tertiary industry. Furthermore, due to endogeneity issues and limited data sources, neither population density nor the proportion of the secondary industry showed significant mediating effects, suggesting that they may not be the primary pathways through which air pollution indirectly affects housing prices.

6 Conclusions and Suggestions

6.1 Conclusions

This article analyzes the impact of different air pollutants on urban housing prices and explores the underlying mechanisms of their relationships. The research findings indicate that air pollution significantly suppresses housing price increases, with varying degrees of impact from different air pollutants, particularly PM_{10} and $PM_{2.5}$, which are the main components of haze. Specifically, for every 10% increase in PM_{10} and $PM_{2.5}$ concentrations, urban housing prices decrease by 1.55 and 3.19%, respectively. Additionally, SO_2 and NO_2 concentrations negatively affect housing prices, but their impact is not significant as urban characteristics increase. Second, an increase in PM_{10} indirectly inhibits housing price increases by limiting per capita GDP and the development of the tertiary industry, both of which exhibit partial mediating effects. Specifically, the mediating effect of per capita GDP accounts for 32.03%, while the mediating effect of the proportion of tertiary industry is 17.21%, indirectly reflecting the negative impact of air pollution on urban economic levels and the development of the tertiary industry. Residents' housing purchases will mainly focus on the current economic development and public infrastructure of the city. The mediating effects of population density and the proportion of the secondary industry on the impact of air pollution on housing prices are not significant.

6.2 Suggestions

This study not only contributes to enriching the theoretical understanding of the impact and mechanism of air pollution on housing prices but also provides guidance for governments in formulating environmental regulatory schemes, which is particularly important in the current context of the continued stagnation of the Chinese real estate market. Specifically, the government can take the following measures to mitigate the suppressive effect of air pollution on housing prices. First, the government can require enterprises to reduce pollutant emissions by enforcing mandatory standards for energy consumption and emissions and imposing environmental pollution taxes or carbon emission taxes on enterprises. Second, the government should strengthen the monitoring of air pollutant emissions, especially haze pollutants, and reduce emissions of PM_{10} and $PM_{2.5}$ pollutants through increased penalties for pollution and enhanced pollution control capabilities. Third, the government should increase awareness of environmental protection and low-carbon living, formulate corresponding policies, encourage individuals to adopt clean energy, reduce reliance on traditional energy sources, and thereby reduce emissions of air pollutants. Fourth, considering the mediating role of the tertiary industry development and the urban economic development level in the relationship between air pollution and housing prices, the government should foster the development of the digital economy, nurture emerging industries, encourage and support the development of the tertiary industry, and promote local economic development through measures such as advancing industrial transformation and improving human capital. These measures can help contribute to the development of China's real estate market.

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