Heliyon 10 (2024) e23469

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

A study on the impact of housing prices on residents' travel frequency and transportation resilience in 35 Chinese cities

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A R T I C L E I N F O

Keywords:
Housing purchase price
Traffic frequency
Transportation resilience
Generalized matrix method

A B S T R A C T

As urbanization proceeds, urban transportation resilience suffers greater challenges. Covering panel data for 35 Chinese cities from 2006 to 2019, after controlling for other variables that may affect urban residents' transportation volumes, this paper finds that rising houseing prices have a significant positive effect on urban residents' traffic frequency. As frequent traffic trips increase the probability of urban residents experiencing disruptions, rising housing purchase prices would have a negative impact on Chinese urban residents' transportation resilience. The regional comparison analysis finds that the regression coefficients of coastal and eastern cities with more expensive housing price are significantly higher than those of non-coastal and western cities with lower housing price, further validating the findings of this paper.

1. Introduction

For many Chinese urban residents, expensive housing and inconvenient transportation are two of the most important issues that plague them. In recent years, with the rapid increase in housing purchase prices around the country, cities' living costs have increased dramatically [1–3]. Based on data from the National Bureau of Statistics of China, China's national average purchase price of residential commercial housing rose from RMB 1948/m^2 in 2000 to RMB 2936/m^2 in 2005 and RMB 4725/m^2 in 2010 and continued to rise to RMB 6473/m^2 in 2015. As of 2019, before the COVID-19 Pandemic, China's national average purchase price of residential commercial real estate had risen to 9287 yuan/m^2. In the 20-year period from 2000 to 2019, except for the only slight decline of approximately 70 yuan/m^2 in 2008 due to the impact of the Asian Financial Crisis, China's national average purchase price of residential commercial real estate increased year-on-year in 19 out of 20 years, reflecting a clear increase in the average purchase price of residential commercial real estate in China. If we look at the country as a whole, the absolute purchase price of residential commercial housing in China in 2019 has not yet exceeded 10,000 yuan/m^2, which still seems to be acceptable, while observing the more densely populated key first- and second-tier cities in China, the purchase price of residential commercial housing is much more expensive, and according to the data from the National Bureau of Statistics of China, as of the end of 2019, just prior to the COVID-19 Pandemic, the average price of new residential units in Shenzhen was RMB 65,516 per square meter, the average price of residential buildings in Shanghai was 54,467 yuan/m^2, and the average price in Beijing was 63,052 yuan/m^2. In the four Chinese top-tier cities, Guangzhou's average residential price was lowest but also reached 35,726 yuan/m^2. However, these values were only the average housing purchase

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https://doi.org/10.1016/j.heliyon.2023.e23469
Received 12 August 2023; Received in revised form 22 November 2023; Accepted 5 December 2023
Available online 9 December 2023
2405-8440/

price in the first-tier cities, and housing purchase prices in the central areas of these metropolises are more than 100 thousand yuan/m^2. Not only are first-tier cities' housing purchase prices expensive, the housing purchase prices in the central areas of many second and third-tier cities, such as Xiamen, Hangzhou, and Nanjing, are also alarming. These prices have reached 30 to 50 thousand yuan/m^2. Although the rate of price increases in China's cities has slowed since 2020 due to COVID-19, the long-term upward trend in housing purchase prices has not changed.

With such expensive residences, citizens constrained by limited incomes may have to rely on long-distance transportation to replace the convenience of living near work and life in the heart of the city with expensive housing purchase prices. This assumption is supported by the data. According to a survey by Baidu Maps, the average one-way commuting distance for workers in Beijing was the longest in China, at 19.20 km, with an average one-way commuting time of 52 min. Shanghai workers' average one-way commute distance was 18.82 km, and the average one-way commute time was 51 min. Guangzhou's average commute distance was 15.16 km, ranking third in the country, and the average one-way commute time reached 46 min. Thus, the daily commute time of workers in these cities approaches 2 h, and residents face long and arduous daily commutes. The three cities with the longest commute times in China: Beijing, Shanghai and Guangzhou, are three of the four Tier 1 cities with the highest housing purchase prices in China. Why is it that the cities with the highest ranked housing purchase price also have the longest commute times for their residents?

The above typical examples from Chinese cities about the relationship between citizens' transportation and housing purchase price make us wonder whether there is a correlation between these two factors in China. To visualize the relationship between these two factors in general, we placed the average price of a square meter of housing purchased by a resident in his/her city, public transportation volume, and private car volume of China in recent years in a graph and attempted to find some regularities. The trend chart also seems to indicate that high residential housing purchase prices are closely related to citizens' public transportation volume and private car volume (Fig. 1). In Fig. 1, we can observe that both the average price of residential housing purchased by Chinese residents and their private vehicle holdings maintained a clear joint upward trend from 2000 to 2019. Public transportation passenger traffic, which covers three modes of transportation, buses, subways, and cabs, also shows a certain joint upward trend with the purchase price of residential housing before 2012 but maintains a relatively flat trend after a drop in public transportation passenger traffic after 2013. Considering the large rise in private car holdings by Chinese residents during this period and the obvious substitution between private car trips and public transportation trips, it still seems intuitive to assume from Fig. 1 that there is a strong link between the price of residential housing purchased by Chinese residents and their travel.

Fig. 1 shows that the housing prices of Chinese citizens and their transportation travel have a common upward trend between 2000 and 2019, and there may be a close relationship between the two. If subsequent statistical validation reveals that high housing prices are indeed strongly associated with more frequent residential transportation trips, then rising housing prices will clearly be detrimental to urban transportation resilience. Since more traffic trips residents have, they are more likely to be affected by various shocks, which include natural disasters such as hurricanes, floods, fires, or human-made events such as terrorist attacks, cultural events, strikes and system failures caused by human error or mismanagement, and accordingly, it will be more difficult for residents to recover from the abnormal state after the shock to the normal state [4].

Although the above data and graph show that the traffic volume and housing prices appear to be intuitively closely related, what is the statistical relationship between high housing prices and residents' transportation frequency and elasticity in Chinese cities? If high housing prices have had an impact on residents' transportation, how large is this impact? Moreover, are there different impact factors

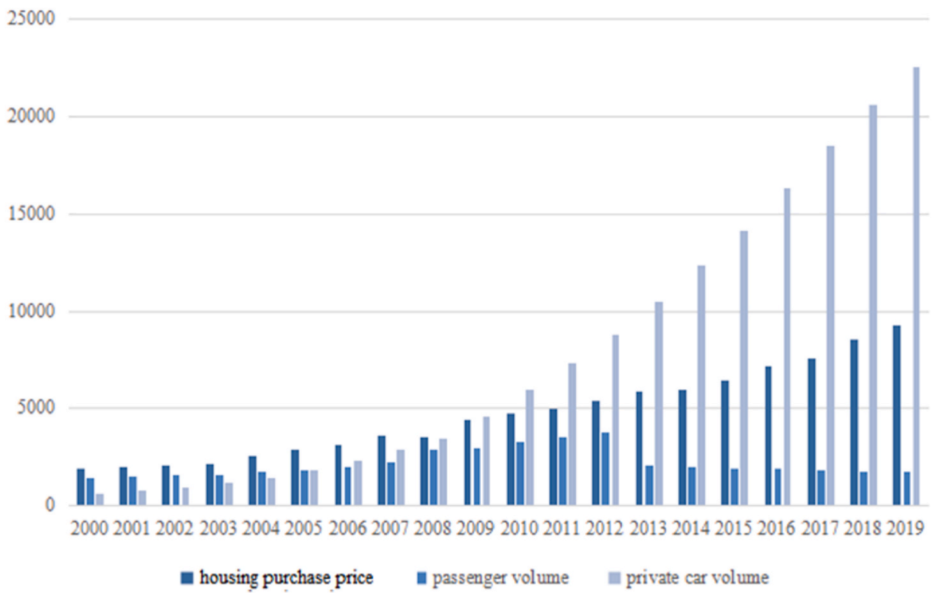

Fig. 1. The average housing purchase price, public transportation and private car volume in China from 2000 to 2019. (Source: China Statistical Yearbook).

for different types of cities? At the same time, while considering that housing price will have an impact on residents' transportation frequency, other factors also affect residents' transportation, such as socioeconomic conditions. How do these factors affect residents' transportation in our paper? If we control the effects of other socioeconomic elements, what portion of resident transportation is affected by the increase in housing prices? Existing studies lack a systematic analysis related to these questions, which is the purpose of this paper.

The innovation of this paper is mainly reflected in the following two aspects. On the one hand, it systematically and comprehensively explores the impact of housing purchase prices on residents' transportation trips on buses, subways, cabs, and private cars in 35 cities in China and finds that housing purchase prices have a significant positive impact on residents' transportation trips in Chinese cities. On the other hand, during the study, the relationship between residents' transportation trips and housing purchase prices in various city types, such as coastal cities and noncoastal cities, eastern cities and western cities, is analyzed in a targeted manner, and comparative analyses are carried out among different city types to determine the different impacts of housing purchase prices on the transportation trips of residents in each type of city.

The institutional arrangement of this paper is shown below. The first part is an introduction. The second part analyzes the related literature in detail. The third part addresses with the methodology of the paper. Section 4 shows the results. Section 5 provides the conclusions and suggestions for future research.

2. Literature review

2.1. Impact of transportation accessibility on housing prices

The literature from different cities in the U.S., China, and other countries shows a significant association between transportation accessibility and high housing prices [5–9]. For example, a study found that the announcement of the Atlanta Beltline program increased the price of nearby housing properties [10]. A study focusing on Athens, Greece, showed that proximity to metro, trolleybus, and rural train stations had a positive impact on property values and rents in the community [11]. For Chinese cities, taking Nanjing as an example, scholars adopted an integrated approach that considers scarcity, accessibility and submarkets and highlighted the impact of urban transport amenities on housing price [12]. How does TOD affect lease payments in Beijing, Shanghai, Shenzhen, Hangzhou, and Wuhan? The spatial preservation model was used to determine the relationship between TOD features (subway stations, neighborhoods and synergies) and lease payments in these megacities, and despite differences among these cities, scholars found that TOD features account for 10–20% of lease payments [13].

Research was conducted on the association of transportation accessibility and accommodation prices by scholars under different traffic modes. Generally speaking, there is a significant association between transportation accessibility and residential prices [6,14–17]. Alonso conducted a normative study on the relationship between housing values and transportation costs and found that housing prices were inverse to the distance from the city center, and areas that were close to the city center had higher rents due to lower transportation costs [18]. Bus accessibility also affects property prices [7,19]. It was found that access to bus stops was positively correlated with real estate prices. For every 500 m from the bus stop, the price of real estate is 0.5% higher. Bus travel time to the basic destination significantly affects housing prices [7]. Studies related to the effects of subways and inner-city railroads on regional housing prices are more common [6,20–24]. For example, the scholars' research suggests that subway departure times that are not too long correlate with property values, other than subway stops, and communities with more than one subway line within an 800-m buffer have higher housing prices than communities without subway lines [24]. Cabs are favored by many residents because they provide a convenient and personal mode of transportation. Additionally, compared to private cars, cabs are a less costly way to travel privately. An academic study interviewed 580 Hong Kong elderly residents to determine whether they would decide to take a regular/accessible cab to non-mandatory social activities in a hypothetical situation [25]. Other studies have also shown that the higher the availability of cabs is, the higher the regional housing price [26,27]. Some scholars have analyzed the impact of the availability of cars on housing price [5,28–30]. For instance, Yu and Zhao (2021) examined the mobility of Chinese rural residents using data from a national survey of 12,524 respondents from 119 towns [30]. The analysis revealed that car ownership was the most important factor influencing transportation for the rural population compared to other factors, as car ownership encourages people to travel to higher-level centers. Generally, existing research has demonstrated that with all modes of transportation, the better the transportation accessibility is, the higher the property price.

2.2. Factors affecting urban residents' transportation

Many factors influence residents' traffic volume. Scholars have discovered that regional passenger traffic is closely related to many indicators of regional economic and social development.

The literature has conventionally reflected that the amount of transportation is extensively linked to gross domestic product [31–34]. For example, scholars have demonstrated the car supply chain using a dataset of reviews received from a prominent Indian car website and found that local GDP has significant impacts on car sales [35]. Meanwhile, many scholarly studies have shown a strong relationship between income and residents' transportation trips [36–38]. Paramati and Roca have found a remarkable active influence of the tourist industry and its interplay with inequalities in earnings on shelter costs in OECD countries [39]. It has also been shown that regional population density and volume have a significant impact on regional transportation demand [40–42]. A study was conducted to determine the variation in ridership between rail stations using IC card data on subway passengers and cellular signal data on the spread of human activity in Shanghai. A data regression was conducted with ridership at every train stop as a causal variable, and the population of the station area was found to be an important explanatory variable [42]. Government finance has an indirect impact on transportation because government spending is partially invested in local infrastructure and public transportation facilities [43–45]. Using a data envelopment analysis, Kyriacou et al. evaluated the capacity of countries based on achieving the greatest amount and use of infrastructure for certain amounts of input and found the governments of the central states in Europe, as well as those of New Zealand and Japan, to be the highest in transportation infrastructural investment and the lowest in Russia, Turkey, and Mexico [45]. Previous studies have also found a strong link between the land area and regional traffic volume [46–48]. Scholars have proposed a method to analyze the relationship between land use and traffic congestion using the macro fundamental diagram (MFD) approach. An important variable in the study is the size of the city area, and the results of the study emphasize the concept of "compact cities" [48]. Prices obviously affect the demand for all modes of transportation [40,49,50]. Scholars have modeled the volume of air passenger traffic in Europe, and studied the effects of high-speed trains, cost-effective aviation and demographic intensity. It was found that a decrease in airfares significantly increased air traffic [40]. Research has revealed that people tend to be inertial in their transportation trips [51,52]. Paix et al. investigated the effect of inertia on trip price sensitivity. According to approximately 90,000 car and public transport trips in the Netherlands, the effect of inertia of individual travel behavior on travel cost sensitivity can be observed [52].

2.3. Urban transportation resilience

Although research on urban resilience has begun to proliferate in recent years [53–60], studies on urban transportation resilience are still in the early stages. In recent years, the concept of resilience has been gradually introduced into the field of urban transportation, and scholars have started to explore the concept of urban transportation resilience and the characteristics of resilient urban transportation [61,62].

Regarding the definition of transportation resilience, scholars have provided different definitions, among which representative definitions include the following: Murray-Tuite [4] defines resilience as a characteristic that indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance needed for restoration to its original functional state. Wan et al. [63] refer to transportation resilience as the ability of a transportation system to absorb disturbances, maintain its basic structure and function, and recover to a needed level of service within an acceptable time and costs after being affected by disruptions. Gonçalves and Ribeiro [62] define the resilience of urban transportation systems as the ability of a system to resist, reduce and absorb the impacts of a disturbance (shock, interruption, or disaster), maintain an acceptable level of service (static resilience), and restore the regular and balanced operation within a reasonable period of time and cost (dynamic resilience). Several studies are also considering how to improve energy efficiency in the transportation sector through appropriate methods, which can also enhance the transportation resilience of residents and cities [64,65].

Scholars measure the resilience of transportation systems by the changes in variables before and after a shock occurrence [8,9]. Commonly measured variables include travel time, travel distance, travel costs, travel flows, etc. For example, using travel time as a measurement variable, if the travel time after the shock is significantly higher than the travel time before the shock, the measured transportation system is considered nonresilient.

This paper differs slightly from the above literature. The variable we use to measure urban transportation resilience is the transportation frequency of urban residents. Our idea is that, after controlling for other variables that may affect residents' transportation

Table 1
Literature compilation.

Variables	Literature on transportation accessibility's impact on housing prices		Symbol	Impact of housing prices on transportation resilience
Total traffic accessibility	[6,14–18]		+	None
Bus accessibility	[7,19]		+	
Metro accessibility	[6,20–24]		+	
Taxi accessibility	[25–27]		+	
Private car accessibility	[24,27,29,30]		+	
Variables	Literature on relevant variables' impact on traffic volume		Symbol on residents' traffic frequency	
GDP	[31–35]		+	
Residents' income	[36–39]		+ or -	
Population	[40–42]		+	
Government Finance	[43–45]		+	
Cities' land area	[46–48]		+ or -	
Price of transportation	[40,49,50]		+ or -	
Inertia of transportation	[51,52,66]		+	
Variables	Literature on transportation accessibility's impact on housing prices	Symbol of transportation accessibility on housing prices	Housing prices' impact on transportation volume	
Housing prices	[10–13]	+	None	

frequency, if an increase in housing price significantly causes an increase in residents' transportation frequency, housing price are considered to have a negative effect on transportation resilience.

2.4. Literature compilation

A sorting of the above literature reveals the main work that has been done and the directions that can be further expanded, as shown in Table 1. First, we find that the driving effect of transportation availability as an explanatory variable on housing price has been relatively abundantly studied. In addition, we sorted out other social and economic factors that affect traffic volumes other than housing price by analyzing the extensive, individual or joint literature to be prepared as control variables for subsequent analyses. Finally, we find that a gap in the literature may be that there is no discussion yet of housing price as an explanatory variable to explore its effect on residents' frequency of travel, controlling for other influencing variables. There is also a lack of literature linking the rise in residential traffic frequency to the greater vulnerability of residents to shocks that reduce their traffic resilience.

3. Methodology

3.1. The research line

Based on the combination and review of literature, the specific research idea of this paper is shown in Fig. 2 below. The starting point of our study is how high or low housing prices will affect residents' choice of residential areas and thus their transportation trips. When housing price are low, residents choose to live in areas close to work and life, travel by foot or bicycle, and have higher transportation resilience. When housing price are high, budget-constrained residents are forced to live in areas far from work and life and travel by frequent buses, subways, cabs, and private cars to counteract the residential crowding-out effect of high housing price, which is the focus of our study. By controlling for other variables that may affect the frequency of residential transportation trips, this paper explores the effect of rising house prices on the frequency of residential transportation trips, and then discusses whether rising house prices have a negative impact on the resilience of residents' transportation.

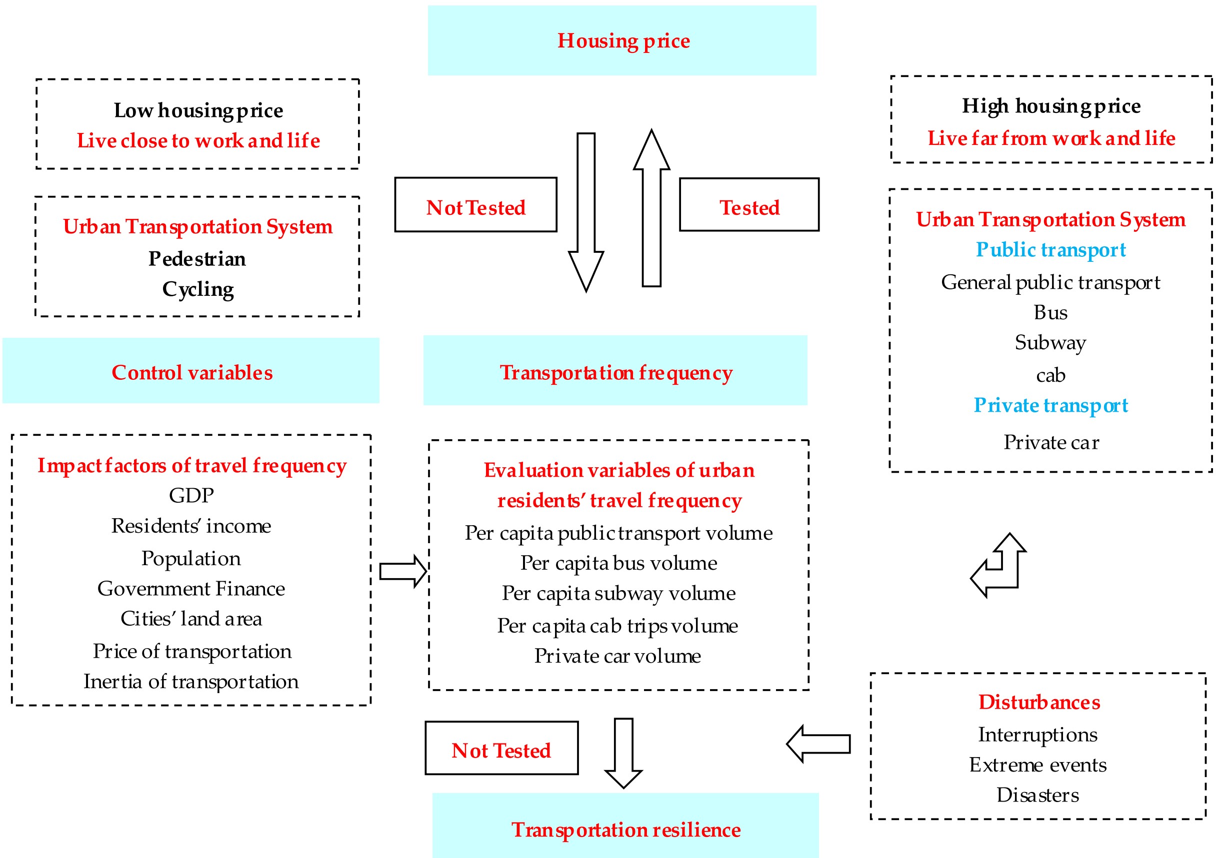

Fig. 2. The research line.

3.2. Estimation model

According to the literature review, taking housing prices and other variables' influence on residents' traffic into account and differentiating among various economic areas of the cities, we can establish the following models:

$$\ln tq_{it} = \alpha_0 + \alpha_1 \ln tq_{it-1} + \alpha_2 \ln hp_{it} + \alpha_3 \ln hp_{it}^2 + \alpha \sum Z_{it} + \mu_{it} \tag{1}$$

$$\ln bus_{it} = \beta_0 + \beta_1 \ln bus_{it-1} + \beta_2 \ln hp_{it} + \beta_3 \ln hp_{it}^2 + \beta \sum Z_{it} + \mu_{it} \tag{2}$$

$$\ln metro_{it} = \gamma_0 + \gamma_1 \ln metro_{it-1} + \gamma_2 \ln hp_{it} + \gamma_3 \ln hp_{it}^2 + \gamma \sum Z_{it} + \mu_{it} \tag{3}$$

$$\ln taxi_{it} = \delta_0 + \delta_1 \ln taxi_{it-1} + \delta_2 \ln hp_{it} + \delta_3 \ln hp_{it}^2 + \delta \sum Z_{it} + \mu_{it} \tag{4}$$

$$\ln car_{it} = \eta_0 + \eta_1 \ln car_{it-1} + \eta_2 \ln hp_{it} + \eta_3 \ln hp_{it}^2 + \eta \sum Z_{it} + \mu_{it} \tag{5}$$

In the above models, tq_{it} is the annual per capita total public transportation volume of city i at year t; bus_{it} represents the annual per capita bus transit volume of city i at year t; $metro_{it}$ represents the annual per capita metro transit volume of city i at year t; $taxi_{it}$ is the annual per capita taxi transit volume of city i at year t; car_{it} is the number of private car ownership of city i at year t; and hp_{it} represents the average price resident pays for one square meter of residential space of city i at year t.

In the above model, since the dependent variable of residential travel has strong inertia, i.e., the dependent variable in the current period will be affected by the dependent variable in the past, the lagged term of the dependent variable of residential travel is added to the model to control the relevant effects. In addition, in order to examine whether there is a nonlinear relationship between housing price and residential transportation travel, the squared term of housing price hp_{it}^2 is added to the model as an explanatory variable.

In the above model, Z_{it} represents the vector of controlling elements, including other factors that impact transit volumes, such as gdp_{it} denotes the per capita gross domestic product of city i at year t, $population_{it}$ denotes the total population of city i at year t, $salary_{it}$ denotes the per capita disposable income for urban households of city i at year t, $finance_{it}$ denotes the per capita local financial expenditure of city i at year t, $rate_{it}$ denotes the level of 3-year loan interest rate for residents of city i at year t, and $land_{it}$ denotes the urban area of city i at year t. μ_{it} denotes independent distributed error terms. In addition, by setting dummy variables, our overall sample is divided into coastal cities, noncoastal cities, eastern cities and western cities.

In terms of how housing prices affect residents' transportation resilience, based on the relevant definitions in the literature review, we have the following assumption.

Hypothesis: After controlling for the other variables that may affect residents' transportation frequency, if an increase in house prices significantly causes an increase in residents' transportation frequency, and increase the probability that residential traffic will be exposed to various shocks, then house prices are considered to have a negative effect on transportation resilience.

3.3. Estimation method

Analyzing the above models, we find that the first-order lag terms of the explanatory variables appear on the right side of the models, showing that they belong to the dynamic panel data model. Potential reciprocal determinate relationships exist between the variables, which results in joint-endogenous problems that must be factored into the estimation. In addition, the error term contains unobservable variables associated with the explanatory variables, which means that the explanatory variables may suffer from endogeneity. For the above reasons, OLS, RE and FE estimations are biased. Therefore, this paper uses the differential GMM model as the estimation method since the model can use variable-level change and differential change information, cope with endogeneity problems arising from the dynamical panels equation, and produce unbiased estimation results [67–69].

GMM estimation is an effective method used to solve the endogeneity problem. And the endogeneity problem of this paper mainly comes from the following three aspects: omitted variables, measurement error, and two-way causality. Regarding omitted variables, this paper examines the factors influencing residential traffic volume, and although a large number of explanatory variables are included, there may still exist a problem of omitting variables. The variables also have the problem of measurement error. Due to the availability of data, this paper sometimes needs to use some proxy variables; for example, we use the one to three-year commercial bank loan interest rate to measure residents' potential traffic cost, which leads to the existence of measurement error. Regarding two-way causality, this paper studies the effect of house prices on transportation trips, but as shown in the literature review, many studies also prove that transportation accessibility has a significant effect on house prices [15,18,29], so there is a two-way causality between house prices and residents' transportation trips. For these reasons, it is appropriate to choose the GMM method to solve the endogeneity in this paper.

3.4. Data

The data in this paper cover the period from 2006 to 2019. The reason for not using data from earlier years is partly influenced by China's welfare housing allocation policy and partly due to the availability of data. Prior to 2000, housing for China's urban residents was mainly allocated based on the welfare housing system. At this time, there was no real estate market, no real estate transactions, and thus no housing prices in China's cities. After joining the workforce, urban residents applied to their organizations for welfare housing according to their age, length of service, status in the organization, number of family members, etc. The organizations provided housing to their employees for free or at a very low price according to the corresponding welfare housing policy. Moreover, under the welfare housing allocation system, since the housing was provided by the resident's work unit, the assigned housing was usually located in or around the unit, very close to the work unit and often within walking distance to and from the unit and home, so there was no problem of transportation commuting. Given this background, our study needs to exclude data from the years in which the welfare housing allocation system was implemented and influenced. At the same time, transportation related variables, such as subway trips and private car ownership data, are only available after 2006 in many cities. Combining these two reasons, this paper selects panels of data from 35 Chinese cities between 2006 and 2019 to study.

Most of the data used in this paper are from the Chinese Economic and Social Development Statistics database, house price data are mainly from the Chinese Real Estate Statistical Yearbook, interest rate data are from the Chinese Central Bank website, and some city data are compared and supplemented using the city statistical yearbook.

Although most of the data are readily available in databases or electronic yearbooks, some errors and omissions occur in these data. For example, some data have obvious errors, and some data are missing from the database and need to be looked up separately in the local city yearbook. To address these problems, we invested considerable time and effort in checking and cleaning the data. For the few data that are still missing after the above process, this paper uses interpolation to fill in the missing data. In addition, to address heteroskedasticity, we use the logarithmic method. Descriptions of the raw data variables before logarithmic processing are shown in Table 2.

4. Results

This section uses empirical measurement models to study the internal mechanisms by which housing purchase prices and other control variables affect residents' travel.

4.1. Impact on urban residents' public transportation

First, we use the differential GMM method to estimate Equation (1). The estimation results are shown in Table 3. The AR(2) statistical results from the estimated models indicate that there is no second-order serial correlation in the model residuals. Furthermore, the Sargan statistical results for every estimated model indicate that the model does not have an overrecognition problem for the instrumental variables, which means that selection of the instrumental variables is sensible.

In Table 3, we display outcomes of GMM regressions for per capita public transportation volume. The regression coefficients indicate that an increase in housing prices will significantly promote residents' public transportation volume, regardless of whether the whole sample of 35 large and medium cities, coastal cities, non-coastal cities, eastern cities, and western cities are considered. The more expensive the housing prices are, the larger the residents' public transportation volume will be. Taking the full sample as an example, for every 1% increase in housing purchase prices, the increase in public transportation volume on 35 major cities will be 1.391%. In coastal and eastern cities, increasing housing prices have an even greater effect upon passenger traffic: each 1% rise of price, the public transportation volume on a person increases by 7.637% and 4.616%, respectively. These results validate our assumption that residential price and residents' public transportation volume has a significant positive relationship: the more expensive cities' housing prices are, the more residents will travel. In cities with low housing prices, such as in Chinese non-coastal and western cities, the coefficients of the influence are much smaller; for example, for non-coastal cities, the coefficient is only 2.838%, which is significantly less than that of coastal cities. These results further confirm the assumptions that high housing prices cause residents to live farther from the city centre, so public travel is more frequent and more difficult, and in municipalities where property values are low, the people are much more probably to live in convenient traffic regions; therefore, the volume of public trips is less affected by housing prices.

Using the regional economic comparative study outcomes at Table 3, it is possible to see the impact of housing prices on public

Table 2
Summary statistics.

Symbol	Variable	Unit	Mean	SD	Minimum	Maximum	Obs.
tq_{it}	Public transportation volume	time/person/year	185.303	81.660	31.659	461.494	490
bus_{it}	Bus traffic volume	time/person/year	126.417	51.762	31.659	331.159	490
$metro_{it}$	Metro traffic volume	time/person/year	41.242	49.993	0.050	216.233	252
$taxi_{it}$	Taxi traffic volume	time/person/year	40.601	21.405	5.818	149.296	490
car_{it}	Private car volume	per 10,000 people	1306.277	805.887	99.466	3694.998	490
hp_{it}	Residential purchase price	yuan/sq. m	8528.886	7006.842	1541	55,769	490
gdp_{it}	Per capita gross domestic product	yuan/person	69932.850	34663.260	13,220	203,489	490
$population_{it}$	City population	tens of thousands	866.487	588.739	145	3124	490
$salary_{it}$	Disposable income per urban resident	yuan	29774.590	13047.830	9335	73,849	490
$finance_{it}$	Per capita financial expenditure	yuan/person	7409.478	5321.869	665.623	29510.300	490
$rate_{it}$	Potential capital costs	%	5.975	0.529	5.375	7.095	490
$land_{it}$	City land area	sq. km	14210.860	14530.550	1569.000	82829.000	490

Source: Chinese Economic and Social Development Statistics database, Chinese Real Estate Statistical Yearbook, Chinese Central Bank.

Table 3
Determinants of per unit public transportation volume.

	Region classification I	Region classification II		Region classification III	
	Whole sample	Coastal	Non-coastal	Eastern	Western
Impact to transport resilience	Negative	Negative	Negative	Negative	Negative
lnhp	1.391*** (0.386)				
lnhp_coastal		7.637** (2.715)			
lnhp_noncoastal			2.838*** (0.802)		
lnhp_east				4.616** (1.682)	
lnhp_west					3.091* (1.538)
$lnhp^2$	−0.074*** (0.021)	−0.400** (0.144)	−0.159*** (0.045)	−0.251** (0.088)	−0.168* (0.087)
lngdp	0.060** (0.021)	0.212 (0.151)	0.100*** (0.024)	0.057 (0.035)	0.093 (0.085)
lnfinance	0.051*** (0.007)	0.297 (0.237)	0.032 (0.021)	0.171 (0.099)	−0.068 (0.054)
lnpopulation	−0.705*** (0.062)	−1.828 (1.412)	−0.747*** (0.062)	0.082 (0.389)	−1.183*** (0.178)
lnland	−0.136***(0.039)		−0.133** (0.045)	−0.648** (0.245)	0.036 (0.316)
L.lntq	0.578*** (0.027)	0.601 (0.337)	0.261*** (0.057)	0.359** (0.126)	0.595*** (0.092)
_cons	0.513 (1.711)	−24.384 (14.334)	−3.865 (3.404)	−13.279* (6.025)	−8.629 (7.861)
P value of AR(2)	0.217	0.517	0.279	0.103	0.8485
P value of Sargan	0.6693	1.000	0.985	1.000	1.000
N	420	120	300	192	132

Notes: Standard errors in parentheses. ***p < 0.01. **p < 0.05. *p < 0.1.

travel more clearly. The elasticity coefficient of housing prices on per capita public traffic in coastal city is 7.637, which is significantly higher than that of non-coastal cities; the elasticity coefficient of eastern cities' housing prices on per capita public transportation volume is 4.616, while for western municipalities, the coefficient is 3.091. This comparison indicates that the elasticity coefficients of per capita public transportation volume in municipalities that have higher house values, for example in coastal and eastern cities, are larger than those of municipalities that have lower house values, such as non-coastal and western cities. The result further confirms our hypothesis that the higher housing prices are, the more obvious the impact on public travel volume. The coefficient on the squared housing price term is significantly negative for all of the models, indicating that an increase in housing prices will cause total urban public traffic to rise more quickly.

As shown in Table 3, after controlling for other variables that may affect the number of residents' public transport trips, under all sample classifications, the increase in house prices significantly leads to an increase in the number of residents' public transport trips, which leads to an increase in the probability of residents' transport encountering shocks and reduces their transport resilience.

The bottom part of Table 3 reflects the impact of other economic variables on per capita public traffic. GDP in per capita shows remarkable active effects in regional public transportation volume, indicating that in economically developed cities, residents' production and living activities are more frequent and consequently increases their traffic trips. The per capita fiscal expenditure variable for the whole sample model positively impacts per capita public transportation volume because some portion of governments' financial expenditures flows into the public transport infrastructure sector for construction and maintenance, thereby improving public transportation conditions and encouraging citizens to use public traffic systems. Therefore, an increase in per capita financial expenditure increases per capita public transportation volume. In the whole sample model, the higher the cost of capital is, the greater the per capita public traffic will be because as capital costs increase, people bear increased pressure in terms of living expenses. As a

Table 4
Determinants of per unit bus volume.

	Region classification I	Region classification II		Region classification III	
	Whole sample	Coastal	non-coastal	Eastern	Western
Impact to transport resilience	Negative	Negative	Negative	Negative	Negative
lnhp	1.238*** (0.233)				
lnhp_coastal		2.178*** (0.568)			
lnhp_noncoastal			1.917*** (0.479)		
lnhp_east				2.592*** (0.579)	
lnhp_west					1.812* (1.005)
$lnhp^2$	−0.071*** (0.013)	−0.120*** (0.026)	−0.112***(0.027)	−0.146*** (0.031)	−0.108* (0.058)
lngdp	0.003 (0.008)	0.009 (0.027)	0.000 (0.015)	0.011 (0.016)	0.084 (0.076)
lnsalary	−0.152***(0.031)	−0.090 (0.068)	−0.073 (0.041)	−0.396** (0.129)	−0.079 (0.107)
lnfinance	0.096*** (0.017)	0.049 (0.068)	0.047 (0.036)	0.330*** (0.091)	
rate	0.034***(0.003)	0.054** (0.016)	0.046*** (0.008)	0.009 (0.011)	0.035 (0.030)
lnland	−0.039 (0.030)	0.100 (0.106)	−0.188* (0.090)	−0.148 (0.221)	−0.490 (0.300)
L.lnbus	0.677*** (0.039)	0.646*** (0.101)	0.624*** (0.066)	0.395*** (0.108)	0.526*** (0.086)
_cons	−2.968** (1.008)	−11.118*** (2.844)	−4.547* (2.248)	−6.226*** (1.883)	−0.833 (5.605)
P value of AR(2)	0.7609	0.9847	0.6559	0.5288	0.9797
P value of Sargan	0.7507	1.000	0.9943	1.000	1.000
N	420	120	300	192	132

Notes: Standard errors in parentheses. ***p < 0.01. **p < 0.05. *p < 0.1.

result, they are more likely to choose public transport instead of private vehicles. Notably, the impact coefficients of city population and land area on public transportation volume are negative. These results appear to be counter-intuitive, but if we analyze the composition of per capita public transportation volume, we can demonstrate its rationality. Since per capita public transport volume is obtained by dividing the cities' total annual public transport volume by the total population, which is already a per capita statistic, a rise in the total urban population at this time would lead to more congestion in the urban public transport system, and thus leads to a decrease in residents' preference for public transport. The reason for the negative city land area coefficient is similar to the previous one: the larger the city is, the higher the time and effort required to switch for commuting via public transportation, which also discourages citizens' demand for public transportation. The hysteresis of per capita public transportation volume is generally significant for the whole sample and most economic regions, indicates that the ratcheting effect of public transportation is substantial and that passengers' current travel strongly correlates with their past travel habits: residents' public traffic behaviour has significant inertial characteristic.

4.2. Impact on urban residents' bus transportation

Table 4 presents outcomes for the per capita bus transit volume of estimate Equation (2). The coefficient results indicate that an increase in housing prices will significantly promote residents' per capita bus traffic volume. Taking the full sample as an example, for every 1% increase in housing purchase prices, the increase in per resident's bus traffic volume will be 1.238%. The elasticity coefficient of coastal city housing prices per capita bus public traffic is 2.178, which is significantly higher than that of non-coastal cities, whose coefficient is 1.917; the elastic coefficient of eastern cities' housing prices on per capita bus public transportation volume is 2.592, while for western cities, the impact coefficient of housing prices is only 1.812. This comparison indicates that the elasticity coefficients of per person bus transit volume in municipalities that have higher house costs, for example coastal and eastern cities, are larger than those of cities with low housing prices, such as non-coastal and western cities. The results confirm our hypothesis that the higher housing prices are, the more obvious the impact on residents' bus travel volume.

The coefficient of the squared housing price term is significantly negative for all of the models, indicating that an increase in house prices will cause citizens' average bus traffic to rise more quickly, which is consisted with our expectation.

As shown in Table 4, after controlling for other variables that may affect the number of residents' bus transport trips, under all sample classifications, the increase in house prices significantly leads to an increase in the number of residents' bus transport trips, according to the former hypothesis, which means an increase residential price reduces citizens' bus transportation resilience.

The coefficients of the effects of other economic variables on per capita bus trips also deserve our attention, especially disposable income, fiscal expenditure and interest rates. We found that the regression results for disposable income are significantly negative, indicating that bus travel remains an important mode of travel for low-income residents. A significantly positive regression result for per capita fiscal expenditure is also revealed, suggesting that public financial investment by cities will enhance hardware and software conditions for urban bus systems, which will further encourage people to travel by bus. A significantly positive regression result for interest rate indicates that residents' bus trips are very sensitive to the cost of capital. The hysteresis of the average number of bus trips is generally significant for the whole sample and all economic regions, indicating that the ratcheting effect of bus transportation is substantial and that passengers' current bus trips strongly correlate with their past travel habits.

4.3. Impact on urban residents' metro transportation

Table 5 shows the differential GMM regression results for the per capita subway transit volume of estimate Equation (3). The metro data are somewhat special, as many cities in China have only opened metros in recent years, and even some central and western cities

Table 5
Determinants of per unit subway transportation volume.

	Region classification I	Region classification II		Region classification III	
	Whole sample	Coastal	Non-coastal	Eastern	Western
Impact to transport resilience	Negative		Negative	Negative	
lnhp	1.758* (0.790)				
lnhp_coastal		1.341 (4.802)			
lnhp_noncoastal			0.611** (0.230)		
lnhp_east				3.193* (1.392)	
lnhp_west					
$lnhp^2$	−0.111** (0.040)	−0.033 (0.238)		−0.180* (0.070)	0.022 (0.029)
lngdp	0.072** (0.027)	−0.151 (0.086)	0.557*** (0.140)	0.008 (0.099)	3.909* (1.867)
lnsalary	1.711*** (0.129)	3.468* (1.469)		1.487*** (0.235)	
rate	0.064*** (0.018)		−0.120** (0.082)	0.054 (0.063)	−2.258* (1.716)
L.lnsubway	0.177*** (0.023)	0.042 (0.088)	0.150*** (0.043)	0.070 (0.038)	−0.425 (0.567)
_cons	−38.673*** (4.315)	49.207 (40.02)	−13.521*** (1.523)	−44.701*** (7.427)	
P value of AR(2)	0.9169	0.1814	0.8180	0.4887	0.1654
P value of Sargan	0.9796	1.000	0.9973	0.9977	1.000
N	182	66	116	105	34

Notes: Standard errors in parentheses. ***p < 0.01. **p < 0.05. *p < 0.1.

have yet to open metros, which accounts for the lack of metro passenger traffic data in many cities in the sample years and leads to some models' inability to provide valid regression results. Still, even from these limited results, we can obtain much inspiration.

The regression results still indicate that an increase in housing prices will significantly promote residents' per capita subway traffic volume. Taking the full sample as an example, for every 1% increase in housing purchase prices, a 1.758% increase occurs in per resident subway traffic volume. And the elasticity coefficient of eastern cities' housing prices on per capita subway traffic is 3.193, which is significantly higher than that of non-coastal cities, whose coefficient is 0.611. Generally, housing purchase prices in eastern cities are higher than those in non-coastal cities are, this result further supports our view, the more expensive house values are, on the other hand, the more pronounced impact on residents' metro travel volume. The coastal and western cities have a small sample size of data because many cities do not have subways or opened them later, preventing valid regression results from being obtained. The coefficient on the squared housing price term is significantly negative for most of the models, indicating that an increase in housing prices will cause citizens' average subway traffic to rise more quickly.

As shown in Table 5, after controlling for other variables that may affect the number of residents' metro transport trips, under the whole sample, non-coastal and eastern sample, the increase in house prices significantly leads to an increase in the number of residents' metro transport trips, according to our former hypothesis, which means an increase in residential price reduces citizens' metro transportation resilience.

Among the other variables that affect residents' metro travel, the regression coefficients are significantly positive for GDP and disposable income. Notably, the impact of disposable income on bus trips are significantly negative, while the effect on metro trips is significantly positive, which may be because metro trips are somewhat more expensive than bus trips. The regression result of a significantly positive interest rate indicates that residents' metro trips are very sensitive to the cost of capital. The hysteresis of the average subway trip number is generally significant for the whole sample and most valid economic regions, indicating that subway transportation's ratcheting effect is substantial.

4.4. *Impact on urban residents' taxi transportation*

The results of estimating Equation (4) for cab transportation are shown in Table 6. Which indicates that an increase in housing prices will significantly promote residents' taxi traffic volume, whether the sample is the whole sample, coastal or non-coastal, or eastern and western cities. Taking the full sample as an example: for every 1% increase in housing purchase prices, the cab trips volume will increase for 3.718%. And in eastern Chinese cities will result in a 4.101% rise in their annual number of cab trips, while a 3.318% rise in western cities. The coefficient on the squared housing price term is significantly negative for all models, indicating that an increase in housing prices will cause citizens' average taxi traffic to rise more quickly.

As shown in Table 6, after controlling for other variables that may affect the number of residents' cab transport trips, under all samples, the increase in house prices significantly leads to an increase in the number of residents' cab transport trips, which means an increase in residential price reduces citizens' cab transportation resilience.

Among the other economic variables that significantly affect the number of cab trips taken by residents, the effect of income is negative, perhaps because if the residents' income rises, they may purchase private cars to travel and thus reduce the number of cab trips. This supposition is also indicated by the significantly positive results of the interest rate regressions that respond to costs of money, where greater costs of money required to purchase a private car is, the more likely that this group of residents will be motivated to choose cab trips. The hysteresis of the average taxi trip number is generally significant for the whole sample and most economic regions, indicating that passengers' current cab trips strongly correlate with their past travel habits.

Table 6
Determinants of per unit taxi volume.

	Region classification I	Region classification II		Region classification III	
	Whole sample	Coastal	Non-coastal	Eastern	Western
Impact to transport resilience	Negative	Negative	Negative	Negative	Negative
lnhp	3.718*** (0.503)				
lnhp_coastal		4.217** (1.297)			
lnhp_noncoastal			3.466*** (1.018)		
lnhp_east				4.101*** (1.068)	
lnhp_west					3.318* (0.932)
$lnhp^2$	−0.199*** (0.028)	−0.213** (0.069)	−0.189** (0.058)	−0.210*** (0.061)	−0.385* (.156)
lngdp	0.006 (0.015)	−0.031 (0.062)	0.040 (0.045)	0.054 (0.032)	−3.281 (1.755)
lnsalary	−0.374*** (0.058)	−0.340 (0.221)	−0.415*** (0.094)	−1.080 (0.597)	4.237 (2.179)
lnafinance	0.178*** (0.026)	0.233** (0.081)	0.156*** (0.042)	0.659 (0.406)	0.207 (.131)
rate	0.074*** (0.011)	0.137** (0.043)	0.062*** (0.016)	0.102* (0.039)	0.415** (.159)
lnland	−0.098 (0.058)	0.175 (0.245)	0.017 (0.394)	−0.061 (0.082)	−6.569* (3.152)
L.lntaxi	0.492*** (0.039)	0.273 (0.213)	0.469*** (0.068)	0.272* (0.134)	0.420 (.325)
_cons	−12.774*** (2.141)	−18.801** (6.706)	−12.005* (6.024)	−12.813 (7.052)	29.366 (30.984)
P value of AR(2)	0.5595	0.4297	0.6057	0.5125	0.1654
P value of Sargan	0.6223	1.000	0.9953	1.000	1.000
N	420	120	300	192	132

Notes: Standard errors in parentheses. ***p < 0.01. **p < 0.05. *p < 0.1.

4.5. Impact on urban residents' private car transportation

Because data on the number of residential private car trips are not available, we collected data on the number of private cars owned per 10,000 people in 35 municipalities as a proxy variable for residential private transportation trips and attempted to discover the effect of rising housing prices on residential private car ownership using a GMM model. The model outcomes can be found at Table 7.

The regression outcome is analogous to that of public transportation trips, the regression coefficient of housing prices on the number of private car ownership is significantly positive. For example, for the overall sample, 1% rise of house price will result in 1.241% rise of personal automobiles for every 10,000 people. The elasticity coefficient of coastal city housing prices on private car numbers is 7.533, which is significantly higher than that of non-coastal cities, whose coefficient is 1.422. Simultaneously, for every 1% increase in housing prices in eastern Chinese cities, residents hold 2.523% more personal automobiles, and residents of western cities hold 2.146% more personal automobiles. The coefficient on the squared housing price term is significantly negative for all models, indicating that rising housing prices will cause resident ownership of personal vehicles to grow faster.

As shown in Table 7, after controlling for other variables that may affect the number of residents' private car holding, under all samples, the increase in house prices significantly leads to an increase in the number of residents' private car, which means an increase in residential price reduces citizens' private car transportation resilience.

Among the other variables that significantly affect the amount of private car ownership, the coefficients of GDP, income and fiscal expenditure are significantly positive, while the coefficients of interest rate and urban area are significantly negative, which aligns with common economic sense. For example, all else being equal, the higher a resident's income is, the more likely the resident is to acquire a private car, and the cheaper the interests rate, that is, less capital is needed to buy the car, the more likely the resident is motivated to acquire a private car. The hysteresis of the private car number is generally significant for the whole sample and all economic regions, indicating that the ratcheting effect for private car transportation is substantial.

4.6. Regional comparison maps of housing prices' impacts on urban transportation

Figs. 3–7 display the regional impact maps of housing prices on various transportation modes, including gross public transportation, buses, subways, cabs, and private cars owned by residents.

Fig. 3 shows the regional impact map of housing prices on gross public transportation. From Fig. 3, we can see that the elasticity coefficient of housing prices on per capita public traffic in coastal cities is 7.637, just as shown in red in Fig. 3, which is significantly higher than that of non-coastal cities in eastern area, with a coefficient of 4.616, similar to the orange color in Fig. 3, while for western municipalities, the coefficient is 3.091, as shown in green in Fig. 3. The blue part in Fig. 3 is the central provincial capital cities, whose coefficients are not focused on in this paper because they are not significant. This comparison indicates that the elasticity coefficients of per capita public transportation volume in municipalities that have higher house values, for example, in coastal and eastern cities, are larger than those of municipalities that have lower house values, such as non-coastal and western cities. The result further confirms our hypothesis that the higher housing prices are, the more obvious the impact of housing prices on public travel volume. The coefficient on the squared housing price term is significantly negative for all of the areas, indicating that an increase in housing prices will cause total urban public traffic to rise more quickly.

Fig. 4 shows the regional impact map of housing prices on bus transportation. In Fig. 4, the elasticity coefficient of coastal city housing prices on per capita bus public traffic is 2.178, as shown in red in Fig. 4, which is significantly higher than that of non-coastal cities, whose coefficient is 1.917, as shown in green in Fig. 4. This comparison indicates that the elasticity coefficients of per-person bus

Table 7
Determinants of private car ownership volume.

	Region classification I	Region classification II		Region classification III	
	Whole sample	Coastal	Non-coastal	Eastern	Western
Impact to transport resilience	Negative	Negative	Negative	Negative	Negative
lnhp	1.241** (0.377)				
lnhp_coastal		7.533* (3.529)			
lnhp_noncoastal			1.422*** (0.396)		
lnhp_east				2.523*** (0.676)	
lnhp_west					2.146** (0.680)
$lnhp^2$	−0.071*** (0.021)	−0.435* (0.214)	−0.082*** (0.022)	−0.116** (0.037)	−0.138*** (0.038)
lngdp	0.057*** (0.016)	−0.027 (0.345)	0.091** (0.035)	−0.011 (0.015)	0.079 (0.047)
lnsalary	0.745*** (0.061)	1.162 (1.012)	0.239** (0.081)	0.411 (0.303)	0.151 (0.220)
lnfinance	0.146*** (0.022)	−0.133 (0.466)	0.041 (0.028)	0.282*** (0.067)	0.046 (0.094)
rate	−0.010 (0.005)	−0.031 (0.139)	−0.003 (0.006)	0.043 (0.026)	−0.043* (0.022)
lnland	−0.228*** (0.044)	−1.197 (1.387)	−0.171** (0.060)	0.471 (0.712)	−0.110 (0.236)
L.lncar	0.353*** (0.018)	0.898* (0.426)	0.696*** (0.062)	0.446** (0.136)	0.648*** (0.101)
_cons	−8.178*** (2.060)	−31.508** (10.813)	−6.056** (2.123)	−17.048** (5.416)	−10.286*** (4.021)
P value of AR(2)	0.193	0.203	0.279	0.493	0.369
P value of Sargan	0.3887	1.000	0.985	0.999	1.000
N	420	120	300	192	132

Notes: Standard errors in parentheses. ***$p < 0.01$. **$p < 0.05$. *$p < 0.1$.

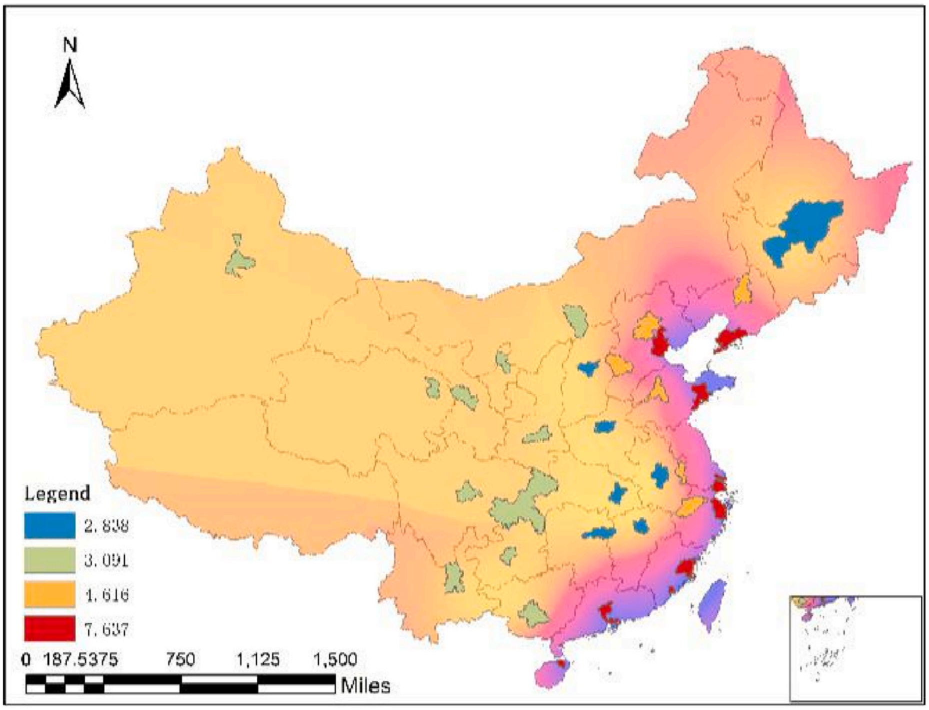

Fig. 3. The impact of housing prices on gross public transportation in different economic regions.

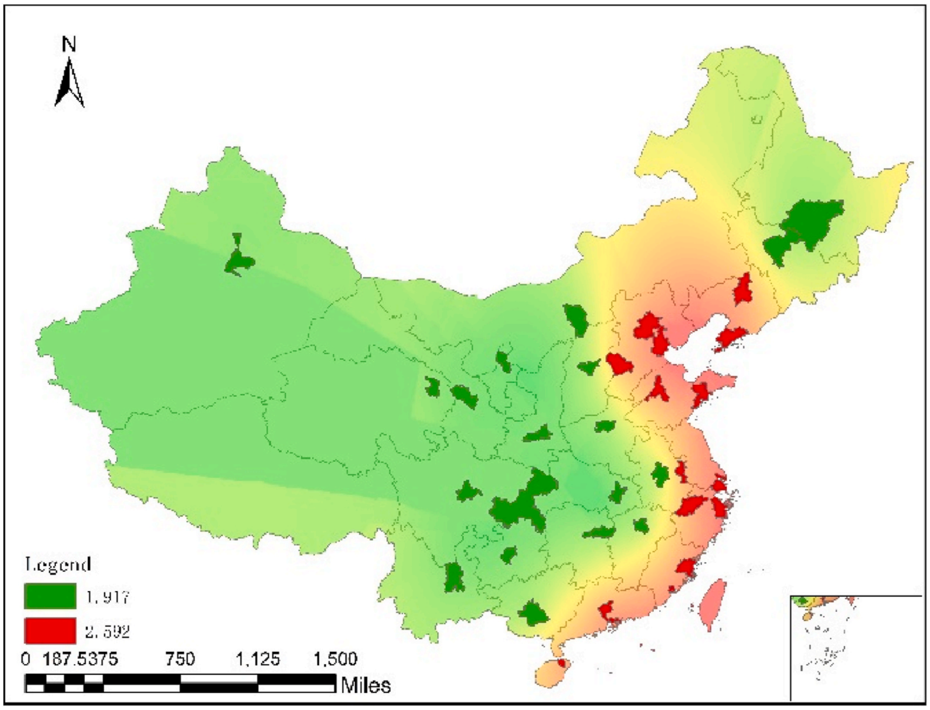

Fig. 4. The impact of housing prices on bus transportation in different economic regions.

transit volume in municipalities that have higher house costs, for example, coastal cities, are larger than those of cities with low housing prices, such as non-coastal cities. The results confirm our hypothesis that the higher housing prices are, the more obvious the impact of housing prices will be on residents' bus travel volume.

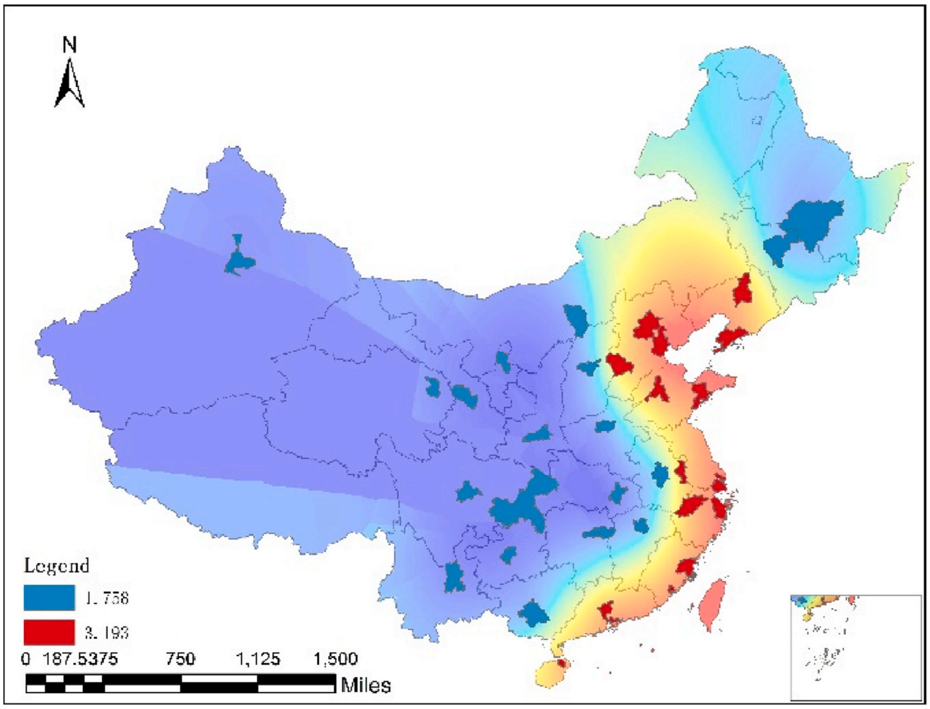

Fig. 5. The impact of housing prices on metro transportation in different economic regions.

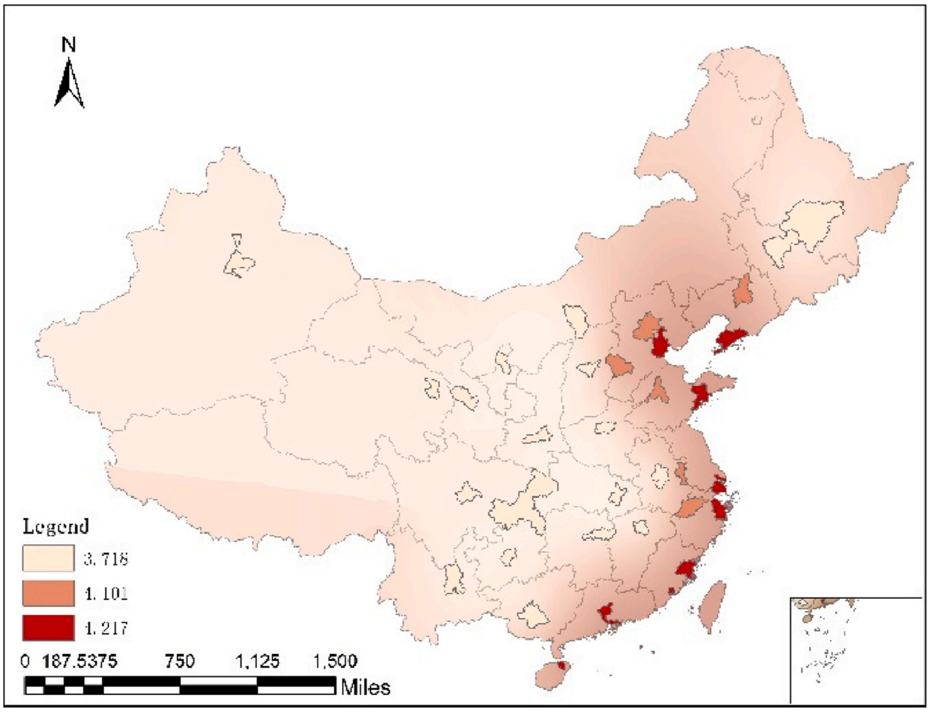

Fig. 6. The impact of housing prices on taxi transportation in different economic regions.

Fig. 5 shows the regional impact map of housing prices on metro transportation. The regional map still indicates that an increase in housing prices will significantly promote residents' per capita subway traffic volume. Taking the full sample as an example, for every 1% increase in housing purchase prices, a 1.758% increase occurs in per resident subway traffic volume, as shown in blue in Fig. 5. The

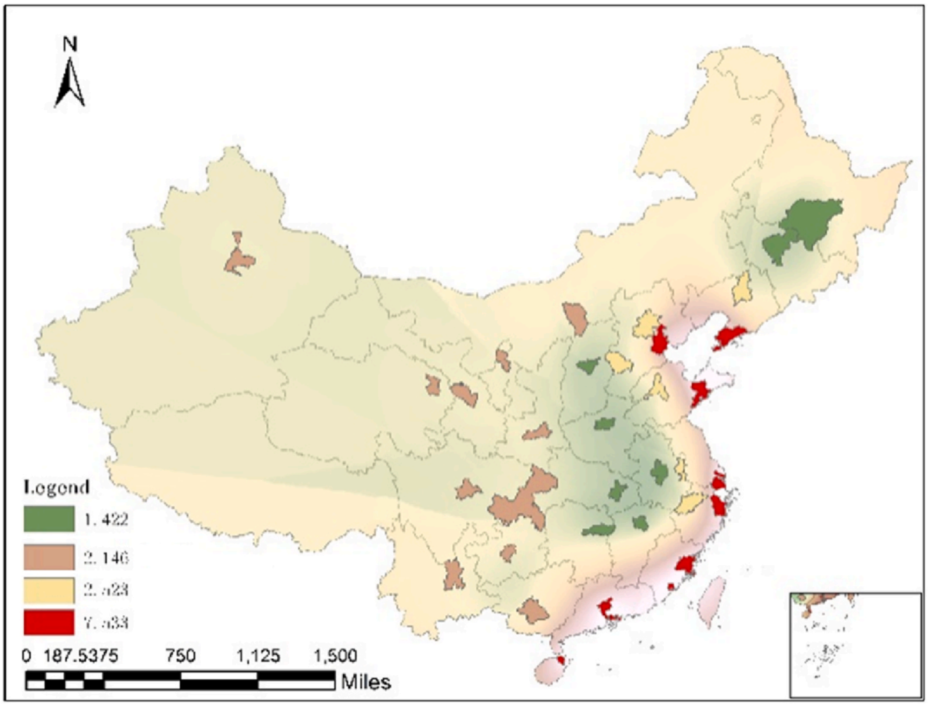

Fig. 7. The impact of housing prices on private car transportation in different economic regions.

elasticity coefficient of eastern cities' housing prices on per capita subway traffic is 3.193, as shown in red in Fig. 5, which is significantly higher than that of the national coefficient, which is 1.758. In general, housing purchase prices in cities in the east are generally higher than those in cities in the central and western areas; thus, this result further supports our view that the more expensive the housing price is, the more pronounced its impact on residents' metro travel volume.

Fig. 6 shows the regional impact map of housing prices on taxi transportation. This indicates that an increase in housing prices will significantly promote residents' taxi traffic volume, whether the sample is the whole sample, coastal or non-coastal, and eastern or western cities. Taking the full sample as an example, for every 1% increase in housing purchase prices, the cab trip volume will increase by 3.718%, which is indicated by the apricot-colored portion in Fig. 6. In addition, eastern Chinese cities will result in a 4.101% rise in their annual number of cab trips, which is indicated by the orange-colored blocks in Fig. 6, while in the eastern coastal cities where housing prices are higher, as indicated by the red-colored blocks in the figure, there is a larger 4.217% rise. Thus, Fig. 6 indicates that an increase in housing prices will cause citizens' average taxi traffic to rise obviously.

Fig. 7 shows the regional impact map of housing prices on private car transportation. As we can see from Fig. 7, the elasticity coefficient of coastal city housing prices on private cars is 7.533, as shown in the red blocks in Fig. 7, which is significantly higher than that of non-coastal cities, as shown in the green blocks in Fig. 7, whose coefficient is 1.422. Simultaneously, for every 1% increase in housing prices in eastern Chinese cities, residents hold 2.523% more personal automobiles, as shown in yellow blocks in Fig. 7, and residents of western cities hold 2.146% more personal automobiles, as shown in pink blocks in Fig. 7. Thus, as we can see from Fig. 7, from the regional impact map of housing prices on private car transportation is analogous to that of public transportation trips, and the impact of housing prices on the amount of private car ownership is significantly positive.

Overall, as demonstrated by Figs. 3–7, housing prices' impact on transportation trips almost always shows the following characteristics: the housing price impact is larger in coastal cities than in non-coastal cities, and higher in eastern cities than in western cities, regardless of the transportation mode. In general, coastal and eastern municipalities have higher housing purchase prices than non-coastal and western municipalities, which further supports our conclusion that cities with high housing prices also show more traffic trips for their residents, and suffer more disturbances and thus with less transportation resilience, so the impact of housing prices on traffic trips is obvious regionally.

4.7. Robustness checks

In this article, we further validate the reliability of the regression results by the following methods.

First, since the original sample data had a large number of missing values, we supplemented the missing values by comparing queries to multiple databases and various city yearbooks for the sake of sample size adequacy. However, for the robustness checks of the results, we conducted a differential GMM test on the unimplemented original data and found that the results were similar in the sign direction and did not differ significantly in the values, indicating that the sample data were robust. Second, the results of the AR(2) tests from Tables 3–7 show that no sequence-related problems occur, and the Sargan statistics show that no problems arise from instrumental variable overrecognition. In addition, to verify the robustness of the regression results under different estimation approaches, this paper uses the dynamic GMM approach to regress the model and finds that regression outcomes are generally compatible with those estimated by differential GMM. Finally, taking into account the difference in data, this paper exchanges residential housing prices with commercial housing prices and finds that there is no fundamental alteration in the sign and significance of the variables. Based on these robustness analyses, it can be determined in general that the outcomes are solid.

5. Conclusions

To discuss the housing prices' impact on residents' transportation, this paper covers the 2006–2019 panel data for 35 Chinese municipalities and discusses housing prices' impact on the following five transportation modes: total public transport, bus, subway, taxi and private car. Moreover, the paper controls for cities' GDP level, citizens' income, population, finance expenditure, interest rate, land area and traffic travel habit, which may influence residents' traffic travel. Then, this paper uses the differential GMM model to estimate housing prices' impact on different local residents' traffic modes and relate outcomes with transportation resilience, meanwhile distinguish the results for different economic regions, such as coastal, non-coastal, eastern and western cities.

Through the study of this paper, we discovered the following important findings. First, the coefficient of the effect of house price on different transportation modes is significantly positive, indicating that the overall amount of public transportation, bus transportation, subway transportation, cab transportation, and private car ownership of citizens will increase significantly with the increase of house price. In addition, the squared term for housing price is significantly positive, implying that residents' transportation trips are a concave function of housing prices, which means that the growth in transportation volume outpaces the growth of the house price. Second, the positive coefficient on house prices for all modes of transportation also suggests that rising house prices will force residents to make more transportation trips, thereby increasing their risk of experiencing various shocks to transportation and reducing their transportation resilience. Third, among the other economic and social variables affecting transportation volume, the coefficient of the city's fiscal expenditure is significantly positive for mass transit options, for instance buses, subways, and the coefficient of citizens' revenue is significantly positive for private modes of travel, such as private cars and cabs. The variables that are significantly negative are mainly interest rates, which measure the cost of capital. And the lagged terms for all modes of transportation are significantly positive, indicates that residents' transportation trips have a strong inertia. Finally, the comparative study of economic regions shows that in regions with high housing prices, such as coastal and eastern cities, housing prices have a greater impact on residents' passenger trips such with less transportation resilience. In regions with lower housing prices, such as non-coastal and western cities, the impact of housing prices is relatively small and has a stronger transportation risk resilience.

There are some policy implications. Firstly, due to the rapid rise in Chinese cities' housing prices, residents living far from their workplaces has caused an increase in passenger travel volume. Thus, residents in cities suffering from higher residential costs at the same time are affected by greater traffic travel pressure, both of which severely reduce their sense of well-being. To solve this problem, the government should first guide housing prices rationally and avoid the crowding effect of high housing prices. In addition, based on our research conclusion, increasing government fiscal expenditures can improve passenger travel conditions and increase public transportation trips, so we suggest that the government uses its financial resources to enhance the transportation infrastructure, improve residents' passenger travel conditions, and increase public transport accessibility, coverage and convenience in cities with high housing prices. Moreover, taking into account that an increase in residents' income levels can ameliorate the conditions and comforts of citizens' travel, local governments should pay attention to improve citizens' disposable income and reducing budget pressure on traffic in municipalities that have higher property prices. According to the results of the comparative study in different economic regions, governments of municipalities that have higher inhabitant accommodation costs, for example coastal and eastern cities, endure much more pressure to improve public transportation.

However, there are some limitations in this paper. For example, since the data used in this paper are urban-level macro data and the data mainly come from national or city statistical yearbooks, in the choice of control variables, we suffer great restrictions. For example, when an individual decides to use a private car, a bus, or other means of transportation, the distance of the trip will be an important variable affecting the decision of the individual, and thus distance should be added as a control variable. In addition, since the type of job a resident has will have an impact on the resident's transportation travel, for example, some jobs allow people to work at home, which reduces the number of times they use public transportation, the type of job a resident has should also be controlled to eliminate its impact on transportation travel if data are available. However, because this paper uses urban macro data, there are no corresponding data on residents' transportation distance, and because the residents' objects in the relating cities' yearbooks are all urban residents, covering all job types of samples, and there are no subcategory statistics on the residents' job types and the corresponding transportation conditions, this paper is not able to effectively control the impact of job types on residents' transportation travel. Therefore, due to the influence of data availability and sample characteristics, the influence of distance and job type is not discussed in the model of this paper and can only be categorized as omitted variables. In the follow-up study, on the basis of this paper's research, researchers can consider carrying out targeted investigation and analysis through microdata and obtaining specific data on residents' transportation distance and job type through more targeted data collection so that the study can analyze the impact of house prices on residents' transportation travel on the basis of better controlling the relevant variables.

Funding statements

This work was supported by the National Social Science Foundation of China under Grant number of 21BJL099.

Data availability statement

The data that support the findings of this study are available from the corresponding author, J. W., upon reasonable request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Biyu Peng: Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Jie Wang:** Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Xiaohua Xia:** Methodology, Formal analysis, Data curation, Conceptualization. **Zhu Ma:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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