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Combined Rental and Transportation Affordability under China's Public Rental Housing System—A Case Study of Nanjing

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Abstract: As a core element of China's housing security system, public rental housing (PRH) has gradually become an effective means of providing low- and moderately low-income groups with viable housing options and is regarded as the embodiment of housing justice values under the Chinese socialist system. Affordability for the groups covered by this system is crucial to its sustainable positive role. By modifying the housing and transportation affordability index (*H&TAI*) equation proposed by the Center for Neighborhood Technology (CNT) and Center for Transit-Oriented Development (CTOD), United States, this paper establishes a novel rental and transportation affordability index (*R&TAI*), introduces transportation-time-cost and comprehensive-transportation-cost concepts and obtains transportation-time-cost data through accessibility analysis, which are incorporated into calculations of comprehensive transportation cost with the ArcGIS spatial analysis software. Based on the ratio of the combined cost of rental housing and transportation to household residual income (RI), this paper studies and measures the combined affordability for low- and moderately low-income residents under the PRH system. The burden of high combined rental and transportation costs not only greatly reduces residents' ability to cope but also limits sustainable PRH system development, exacerbating the gaps between social strata. This study and its conclusions provide a reference for the Chinese government for reforming the macro-housing system and practically regulating the housing market while providing residents with options to reduce their comprehensive burden and improve their quality of life.

Keywords: public rental housing system; transportation time cost; low-income households; renting and transportation affordability index

1. Introduction

Reform of the Chinese housing security system began around 1998 [1]. The initial system mainly included systems for a housing provident fund, indemnificatory housing and low-rent housing [2]. As China continues to reform its housing security system, public rental housing (PRH) has become an increasingly core element. PRH is mainly aimed at low-income groups in cities [3]. To a certain extent, the PRH system is able to avoid several typical housing issues, including rent seeking, an unfair distribution of housing resources across indemnificatory housing markets, limitations on household registration and threshold discrimination in low-rent housing [4]. The system tends to be regarded as upholding fair housing [5] principles and effectively realizing the goal of providing

low-income residents with a home [5]. This also promotes the gradual upgrade and transformation of the Chinese housing consumption pattern from a sales-oriented to a rent-oriented pattern, thereby reflecting the housing justice values of having a home [6] and of housing intended for living rather than speculation [7,8] under the Chinese socialist system.

The PRH system will continue to be optimized and play a positive role. Affordability for the targeted groups is the key to whether the system can sustainably play a positive role. The PRH system should be directly linked to housing affordability for residents (Lu, W.M. and Yao, W.J., 2011) [9] because only in this way can housing resources be more equitably and rationally allocated. If the resident groups targeted by the PRH system cannot afford the provided housing options, this policy will lose its purpose and ability to be sustainably developed.

The concept of affordability originated from a study of household budgets in the 19th century [10]. In 1857, the German statistician and economist Ernst Engel first used the expenditure-to-income ratio to study the ability of households to afford housing (Engel proposed that housing expenditure did not change with income) [11]. Housing affordability means that a household can buy or rent a house at a certain price that will not put an unreasonable burden on the household [12]. Modern discourse on housing affordability originated in the 1980s and 1990s [13]. As a result, the governments of the United Kingdom, the United States and Australia, among other countries, all began to consider housing affordability as a focus of their housing plans [13–16]. Traditional research on housing affordability has usually measured the ratio of housing prices to income over a certain period [17–19]. Most such studies have been performed from the perspective of median-income families [20] acquiring housing property rights but there have been few studies on the affordability of rental housing. More recently, scholars have proposed looking beyond median income when investigating the affordability of housing [21]. However, perhaps due to the small number of low-income groups and the relatively brief developmental history of the PRH system, there is limited academic research on low-income groups and PRH affordability. The Chinese researchers Hu and Wang (2012) contributed a useful study on the affordability of rental housing with regard to low-income groups in Shanghai based on market prices. Their results led them to conclude that low-income groups in large cities experience major limitations to their ability to pay due to monetary insolvency. As such, it is difficult to resolve the housing problem by requiring such groups to rely on themselves to purchase rental properties [22]. One possible solution may be to encourage low-income urban groups to rent under the PRH system, which is a quasi-public good with a notable welfare character. In practice, the rental prices of PRH options tend to be far lower than those of similar market-based options. Subsequently, research using market-based rental housing prices in its base measurement of affordability for low-income groups may misrepresent their true ability to afford housing.

Ernest Uwayezu and Walter T. de Vries focused on housing availability for low-income urban residents [23] but they ignored the impact of spatial and regional factors on affordability. As urbanization accelerates, the low-density development mode of the outwardly growing suburban areas of cities greatly reduces accessibility for many residents and increases their long-distance commuting and transportation costs [24,25], thus generating problems of spatial justice [26,27]. Therefore, only considering housing expenditures could largely misrepresent affordability for residents. Such assessments should fully reflect the total costs these households must pay to realize their basic housing needs rather than only consider their housing costs. Otherwise, these assessments could be prone to distortions. Yang et al. (2013) noted the problem of the transportation accessibility of housing and researched the accessibility of PRH [28]. However, as their research separated affordability and accessibility, they were unable to provide a comprehensive conclusion, making it difficult to assess the impact of transportation costs on comprehensive affordability. In 2006, the Center for Neighborhood Technology (CNT) and Center for Transit-Oriented Development (CTOD) in the United States simultaneously proposed the idea of assessing housing affordability by considering both housing and commuting costs and thereby created the housing and transportation affordability index (*H&TAI*) [29]. This index assumes that the total cost of a given housing option includes both its

direct housing costs and its transportation costs, with the final value being the ratio of the sum of the housing and commuting costs to household income, calculated as follows: *H&TAI* = (housing costs + commuting costs)/household income. This research concept proposed by the CNT and CTOD offers a more realistic and accurate standard for the measurement of housing affordability and has been gradually recognized by international scholars [30–34]. In practice, the *H&TAI* has also been utilized by city managers, with Chicago even adopting this index as a basis for its City 2040 planning program [35]. However, the housing costs in the CNT and CTOD formulation are based on the monthly housing expenditure of median-income families. In 2012, the Center for Housing Policy and CNT collaborated on a new report [36], gauging the housing and transportation cost burdens of moderate-income households living in the 25 largest metropolitan areas but ignoring the rental housing demand of low-income residents. Moreover, only direct monetary costs were considered in their transportation cost variable, which lacks the consideration of any time-cost factor within the true transportation costs.

Since the 20th century, following the rise of metropolitan areas and urban agglomerations, Chinese city managers have increasingly solely focused on expanding and developing urban fringes [2], while urban development has generally exhibited polycentricity and suburbanization trends. Noting these features, Chinese scholars have started to reflect on the completeness and rationality of measuring affordability in terms of housing costs alone and have researched the comprehensive affordability of housing and transportation costs for residents in certain major Chinese cities, such as Beijing [37] and Nanjing [38]. By also considering transportation time costs in these studies, researchers have helped to greatly advance the current understanding of the comprehensive affordability of transportation and housing in China. However, there also remains within this research a lack of classification and stratified analysis; thereby, the distinctions of low-income groups, indemnificatory housing and rental housing affordability are ignored.

Based on the above review of the existing research, this paper believes that there may be two limitations of traditional affordability research: one is the lack of consideration of low-income residents and the rental housing system [39]; the other limitation is the lack of consideration of the impact of location costs, especially transportation costs, on affordability [19]. This paper selects the PRH system and low-income residents as research objects, seeking to combine these two aspects to conduct in-depth and innovative housing affordability research. The housing affordability for PRH system-targeted residents mainly depends on two factors, namely, rental and commuting costs. Similarly to the studies of Chinese scholars [37,38], also this paper considers comprehensive travel cost and modifies *H&TAI* research framework, the rental and transportation affordability index (*R&TAI*) of PRH is established, the *R&TAI* is investigated for low- and moderately low-income groups covered by the PRH system in Chinese cities and the factors influencing the sustainable development of the system are examined. In relation to previous research, this study is novel in the following main aspects:

The first novel aspect is the modification of the *H&TAI* to create the *R&TAI*, which is then adopted as the main metric to examine the combined renting and transportation costs. The index's value is the ratio of the household's comprehensive burden of rental housing (namely, direct rental costs combined with associated transportation costs) to the household's residual income (*RI*).

The second novel aspect is the introduction of the concept of comprehensive transportation costs due to the residential location, which includes direct monetary costs as well as transportation time costs and the incorporation of these costs into the calculation of the comprehensive burden of rental housing. With the use of travel questionnaire surveys and traffic network data [40], this paper analyzes the transportation time costs for microscale transportation communities as its spatial unit.

The third novel aspect involves the application of the *R&TAI* model to a case study on low- and moderately low-income urban households covered by the PRH system, thus helping to bridge the research gap regarding comprehensive affordability for low- and moderately low-income groups and indemnificatory housing and thereby advancing the completeness of housing affordability research.

The rest of the paper is organized as follows. In Section 2, we introduce the case study city and the study area. Among Chinese cities, Nanjing is very representative and suitable for quantitative and qualitative analysis. The nine administrative districts located in the main urban area of Nanjing comprise the research scope. In Section 3, we construct the *R&TAI* model and the calculation method of each variable is explained, including the rental cost, transportation cost and household RI and Section 4 presents the results. The combined renting and transportation affordability for low- and moderately low-income residents within the PRH system is then measured and analyzed according to the described methods. On the basis of the quantitative research results, we examine the results and highlight future research directions in Section 5, drawing conclusions in Section 6.

2. Study Area and Data Sources

2.1. Study Area

This paper selects Nanjing as a case city for the quantitative and qualitative study of the combined renting and transportation affordability of the Chinese PRH system. Among Chinese cities, Nanjing is very representative, mainly because of the following characteristics:

Nanjing city has high levels of comprehensive strength and urbanization, as well as a large scale. As the political center of Jiangsu Province and a core city in the Yangtze River Delta Urban Agglomeration, Nanjing is an open city with high market activities located on the east coast of China. In the Yangtze River Delta Urban Agglomeration Development Plan [41] issued by the Chinese government in June 2016, Nanjing was defined as the only mega-city in the Yangtze River Delta Urban Agglomeration and within the broader eastern China region, it is second only to the mega-city of Shanghai (Figure 1).

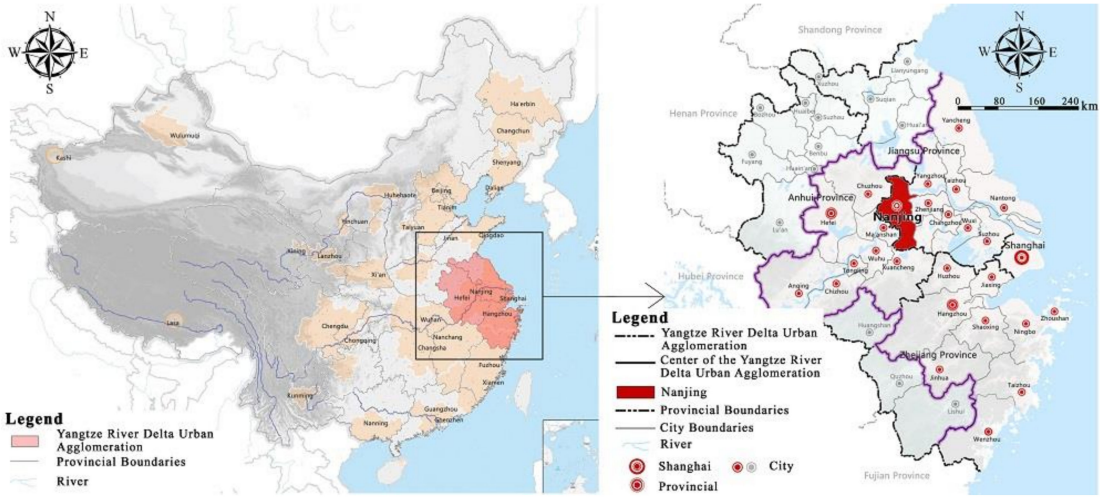

Figure 1. Nanjing, a city in the Yangtze River Delta Urban Agglomeration, China.

Nanjing's population is highly mobile and regarded as a high-quality group of moderate scale. Being in a state of natural growth, the permanent resident population of Nanjing reached 8.5 million in 2019 [42]. Due to its high urban comprehensive strength and superior business environment, Nanjing has become a major site of population inflow within China, along with which the population's inelastic demand for housing continues to expand, while viable housing resources, in turn, become scarcer.

Nanjing's urban space is expanding and transportation costs are increasing. In recent years, with the continuous adjustment of Nanjing's administrative divisions and the expansion of its internal spatial structure around the city, Nanjing, as a mega-city, has exhibited polycentric development characteristics. This can be clearly observed upon reviewing the development of many of the city's outer districts, which now have developed into distinct city centers such as Jiangning, Jianye Hexi, Xianlin and Pukou Jiangbei New District. As a result, Nanjing represents a clear case of increasing

distances between residents' workplaces and homes, while the increasing urban population has, in turn, aggravated urban traffic congestion and the commuting times and transportation costs for Nanjing residents.

The scope of this study primarily includes the nine administrative districts located in the main urban area of Nanjing (Figure 2). Home to 89% of the city's population, these combined districts cover approximately 755.6 square kilometers in total, with a high population density and intensive human activities. These nine administrative districts can generally be grouped into two main categories: those in the central area south of the Yangtze River, including Gulou, Xuanwu, Qinhuai, Qixia, Yuhuatai, Jianye and Jiangning districts and the two outer areas located north of the Yangtze River, namely, Luhe and Pukou districts (Figure 2).

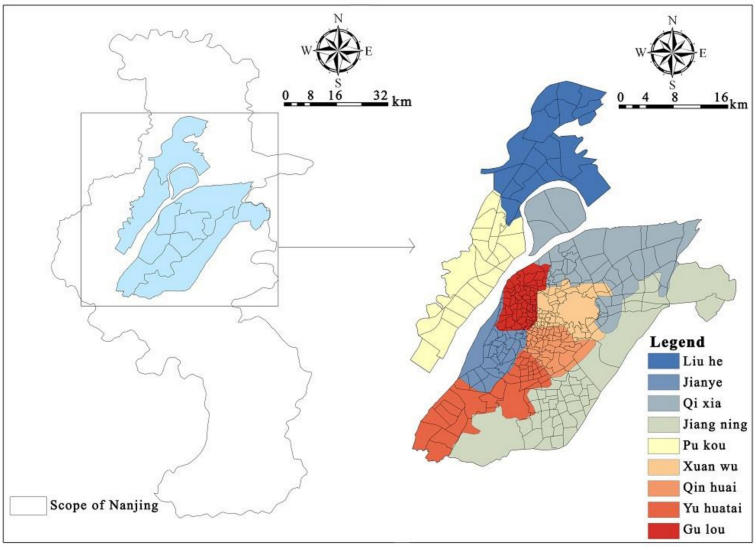

Figure 2. Overview of Nanjing's administrative divisions and research scope.

2.2. Data Sources and Processing

This study uses data obtained from three primary sets of sources:

(1) Data from the Nanjing Annual Statistical Bulletin of National Economic and Social Development (hereinafter referred to as the Statistical Bulletin) and the Statistical Yearbook of Nanjing. In the course of this study, original data such as per capita disposable income and its hierarchical groupings, per capita household population and consumer expenditures, were all retrieved from the Statistical Bulletin and Statistical Yearbook.

(2) Data from official statistics and documents issued by the Nanjing Municipal Commission of Development and Reform, Nanjing Housing Security and Real Estate Bureau and Nanjing Transportation Bureau. The rental price data for the PRH system were acquired from the Nanjing Municipal Development and Reform Commission and the Nanjing Real Estate Administration Bureau, while the basic data for calculating the direct monetary traffic costs were obtained from the Nanjing Transportation Bureau.

(3) Traffic questionnaire data. The basic data adopted to estimate the transportation time costs in this paper originate from the Nanjing Residents' Traffic Travel Survey (hereinafter referred to as the Traffic Survey) conducted by the Nanjing Traffic Development Annual Report Preparation Group in October 2019. The survey divided respondents into different urban spaces according to their transportation community and the questionnaire consisted of four sections: (1) basic household characteristics, including address, family structure, vehicle ownership, annual household income and vehicle purchase intention; (2) the personal characteristics of the residents, including gender, occupation, age and educational background and whether the resident held a transportation

card and driver's license; (3) residents' daily travel survey records, including travel sequences, departure times, departure addresses and their nature, travel purposes, travel modes, destination addresses and their nature and arrival time; and (4) opinions and suggestions on urban transportation. A working day (Wednesday) was chosen to conduct a random household survey of the residents in the nine districts of the main city of Nanjing. The surveys were performed on 40 streets selected from the city's seven centrally located districts, including Gulou District, Xuanwu District, Qinhuai District, Jianye District, Qixia District, Yuhuatai District and Jiangning District, while five streets were selected from the two outer areas of Pukou District and Luhe District, resulting in a total of 45 streets. Valid questionnaire data from a total of 1999 households and 5930 individuals were collected, covering 470 distinct transportation communities and including 15,389 pieces of valid data. In the course of this research, relevant data on the residents' one-day travel survey records were extracted from the Traffic Survey database and then statistically and spatially analyzed with ArcGIS to process the valid data and calculate the transportation-time costs.

3. Methods

3.1. Research Framework

Based on the empirical analysis of the combined affordability for the PRH system-targeted groups (including low-income and lower-middle-income residents and their households) in a representative case study city, this study investigated the impact of the sustainable development of the PRH system and reached several important conclusions (Figure 3).

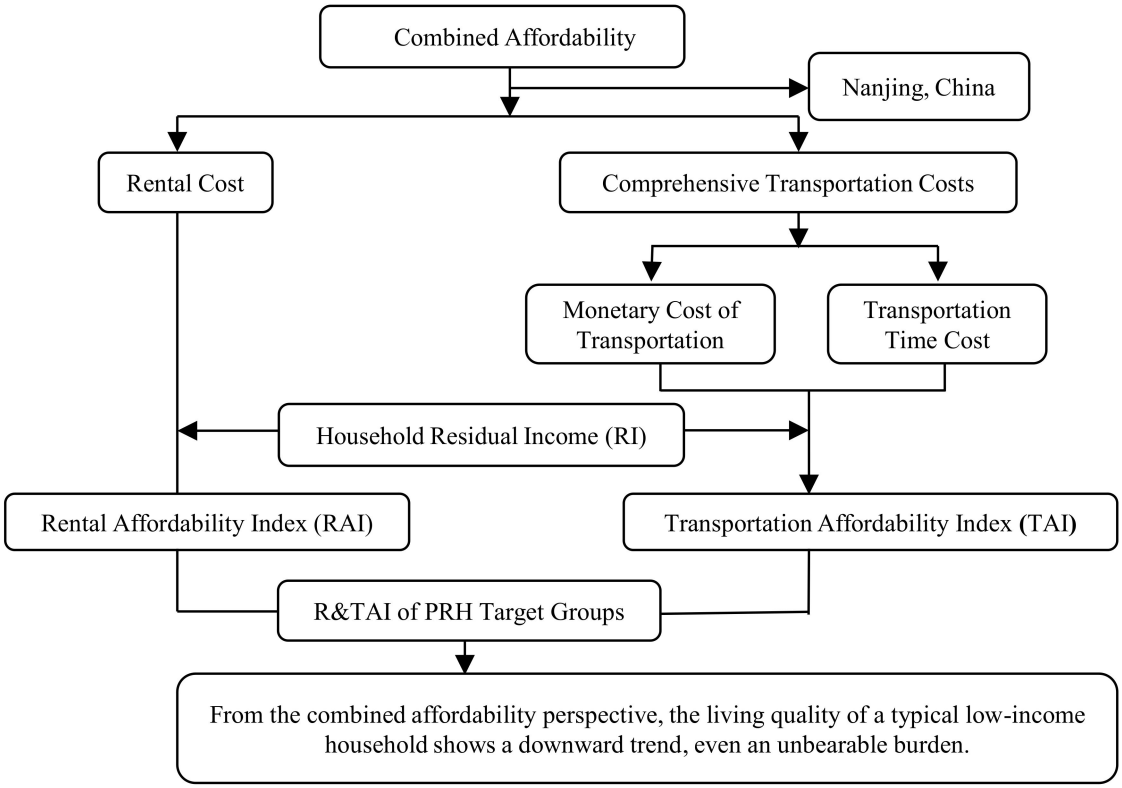

Figure 3. Application of the research concept of combined affordability to the public rental housing (PRH) system.

3.2. Constructing the R&TAI

In 2006, the CNT and CTOD proposed assessing housing affordability through the combined consideration of both direct housing costs and associated commuting costs and thereby constructed the *H&TAI*.

$$H\&TAI = \frac{HC + TC}{HI.} \tag{1}$$

Under the *H&TAI*, *HC* are the housing costs, which are based on the median value of the monthly expenditures of a certain group of homeowners, including mortgage payments, property taxes, housing insurance and property rights fees. *TC* are the transportation costs. Because only such costs for commuting purposes are calculated, they are also recorded as the commuting costs, the direct monetary costs of transport for commuting purposes. Finally, *HI* is the household income, which is the median annual income of middle-income households [29].

This paper modifies and optimizes the three variables of the *H&TAI* as follows:

(1) The rental cost (*RC*) replaces the *H&TAI*'s housing costs. As this study's topic is the comprehensive affordability of the PRH system, housing costs based on ownership costs are no longer relevant and they are replaced by the direct RCs of PRH.

(2) TC_{m+t} replaces the *H&TAI*'s commuting costs. This new formulation includes both the direct monetary costs (TC_m) of commuting and transportation time costs (TC_t). The time cost, also known as the time value, refers to the time spent by individual residents in the process of transportation, including transport, transfer and wait times. The value of this time is derived from the existence of the individuals' corresponding opportunity costs [29].

(3) The household RI replaces the *H&TAI*'s household income. The *RI* is the household's total residual net income after deducting the minimum nonhousing and living expenses over a certain period of time. Compared to previous research on the comprehensive affordability of housing and transportation, this paper adopted the *RI* of low-income households to measure affordability. This was conducted for several reasons, including aiming to create a more humane and rational household consumption model, studying the range of affordable rental options for low-income households that do not affect their basic living standards and emphasizing not only demand for more appropriate residential housing but also other basic necessities, including food, clothing, communication, education and medical care. Therefore, low-income households can also apply this model to better predict whether a certain housing option's comprehensive affordability value may risk leading them into poverty.

Following the abovementioned modifications, the revised *R&TAI* equation is as follows:

$$R\&TAI = \frac{RC + TC_{m+t}}{RI}, \tag{2}$$

where *RC* is the rental cost, TC_{m+t} is the comprehensive transportation cost and *RI* is the household *RI*.

To compare the changes in affordability before and after the incorporation of transportation costs, this paper also separately calculates the rental affordability index (*RAI*) and transportation affordability index (*TAI*) of PRH.

The *RAI* and *TAI* equations are as follows:

$$RAI = \frac{RC}{RI} \tag{3}$$

$$TAI = \frac{TC_{m+t}}{RI}. \tag{4}$$

The associated calculations may be divided into two steps. First, the values of the three variables *RC*, TC_{m+t} and *RI* are calculated, after which the *RAI*, *TAI* and *R&TAI* are determined and comparatively analyzed.

3.3. Calculating the Household Residual Income (RI)

Assume that over a certain period of time, a low-income household's expenditures can be divided into two categories: housing-related expenditures and other nonhousing, basic-necessity expenditures. The latter category is assumed to include the following expenditure subtypes: food, clothing, household equipment supplies and services, healthcare, communications, education, cultural entertainment and recreation and other goods and services. On the premise that these basic-necessity expenditures should not be compromised for the sake of the housing-related expenditures, the amount remaining they are deducted from the original net income over this period represents the maximum amount households should be able to rationally spend on housing.

As such, the *RI* of the household can be expressed as

$$RI = Y - \sum_{k=1}^{n} P_i X_i \times \varepsilon, \tag{5}$$

where *RI* is the household *RI* of residents; P_i is the market price of category I consumer goods over the given period; $P_i X_i$ is a certain type of consumption expenditure (i); Y is the average disposable income of each household; ε is the number of people in the different households; $i = 1, 2, \cdots, n$ $\sum_{k=1}^{n} P_i X_i$ is the total nonhousing, basic-living expenditure of a household over a certain period of time; and $Y - \sum_{k=1}^{n} P_i X_i$ reflects the *RI* of households after their consumption expenditure on nonhousing basic needs, whose surplus can be applied to cover other expenditure needs.

According to the residents' consumption preferences and trends, this part of the *RI* could result in increases in one type or several types of consumption by a certain proportion. However, it is assumed here that households first consider using this part of their *RI* for comprehensive expenditure on rental housing.

3.4. Comprehensive Transportation Costs (TC_{m+t})

In this paper, the comprehensive transportation costs only consider the commuting costs, rather than other transportation-related needs and preferences. These commuting costs are calculated on the basis of 22 working days per month. The equation is as follows:

$$TC_{m+t} = TC_m + TC_t, \tag{6}$$

where TC_m are the transportation monetary costs and TC_t are the transportation time costs.

The calculation of the transportation monetary costs involves two travel modes for commuting to work: public transportation and private vehicles. According to the empirical method, the costs for commuting by public transportation can be calculated according to the median public-transportation costs in a given city. The costs of commuting with private vehicles include the vehicle purchase, insurance, fuel and parking costs.

To calculate the transportation-time costs, valid data related to travel for commuting purposes were retrieved from the residents' one-day travel survey records and the associated transportation communities were adopted as spatial units. With the use of the ArcGIS spatial analysis software, accessibility evaluation was performed for the average travel time for these transportation communities and the transportation-time costs could thus be calculated.

It should be noted that private vehicle travel and public transportation (including urban rail transit) are the main travel modes for residents with regard to the calculation of the transportation-time costs, while the time costs associated with the walking and cycling transportation modes are included in the wait time costs, for comparison between the different transportation modes.

Following these calculations, the time costs were converted into an estimated monetary equivalent. The World Bank's recommended time-cost coefficients for such calculations are 1.33 for business and

work trips, 0.15 for school trips and 0.3 for other nonwork trips [43]. As such, the transportation-time costs in this study were calculated according to a time-cost coefficient of 1.33, as expressed in the following equation:

$$TC_t = TM \times 1.33 \times HW, \quad (7)$$

where TC_t is the monetary cost equivalent of the transportation time cost; TM is the total transportation time, namely, the total commuting time; and HW is the commuter's hourly wage.

3.5. Setting Evaluation Criteria

Current research on affordability usually relies on the ratio of housing expenditures to total income. Based on historical, institutional and social values, among other factors, most researchers have assumed 25% or 30% as the standard of what should be considered affordable [16] under such formulations. Scholars have also adopted 50% as the basis to judge whether a family experiences a serious housing-expenditure burden [44]. As another point of reference, to control financial risks, both domestic and foreign banks often apply the standard whereby a monthly loan amount should not exceed 50% of an individual's monthly income as the basis for whether to issue loans [18]. In the study of the CNT and CTOD, 50% was also adopted as the corresponding evaluation standard for affordability [29].

In this paper, as part of considering both the nonhousing, basic-needs expenditures and housing expenditure needs of low-income households, the *RI* involved in the affordability calculation has already excluded the nonhousing, basic-needs expenditures, so it is assumed that all of the *RI* may be used toward housing expenditures. Therefore, the evaluation standard for comprehensive affordability in this paper is naturally distinct from the traditional standard described above. As such, $R\&TAI = 1$ is adopted as the standard to evaluate whether a housing burden is unbearable. When $R\&TAI = 1$, this implies that the household spends 100% of its RI on rental housing and comprehensive transportation costs, indicating that the overall burden has already reached a critical level. Selecting the above as the evaluation standard's primary threshold, the evaluation is further divided into five levels (Table 1). The larger the *R&TAI* proportion, the higher the overall burden on the household and, correspondingly, the lower the comprehensive affordability. Conversely, the smaller the *R&TAI* proportion, the lower the overall burden on the household and the higher the comprehensive affordability. When a household spends more than 100% of its *RI* on rental housing and total transportation costs (i.e., $R\&TAI > 1$), there are two likely possibilities. One is that the household is put under pressure and must decrease its nonhousing, basic-needs expenditures in order to continue to cover the rental housing costs, resulting in an increasingly smaller share of the living costs relative to the overall expenditure. The other possibility is that the household increases its household debt burden in order to continue to cover both its rental housing costs and its normal level of nonhousing, basic-needs expenditures. Both possibilities suggest that the overall burden on the household is excessive and may lead it into poverty.

Table 1. Evaluation criteria for the rental and transportation affordability index (*R&TAI*).

R&TAI	**Below 0.2**	**0.2–0.4**	**0.4–0.6**	**0.6–1**	**Higher than 1**
Burden Status	No burden	Light burden	Medium burden	Heavy but bearable burden	Unbearable

The individual evaluation of the *RAI* and *TAI* is also conducted according to the five levels mentioned above.

4. Results

4.1. RI of the Target Groups under the PRH System in Nanjing

The Nanjing Statistics Bureau considers per capita disposable income as an indicator and divides households into five levels: low-income, lower-middle-income, middle-income, upper-middle-income and high-income households. According to these, this paper selected low-income and lower-middle-income households as its quantitative research subjects and their relevant data were prepared, including the number of households, average number of people per household, per capita disposable income and basic household consumption. With the use of these data, the two groups' nonhousing, basic expenditures and RI were calculated (Table 2).

Table 2. Residual income (*RI*), of the low-income and lower-middle-income households in Nanjing.

Items	Low Income (CNY)	Lower-Middle Income (CNY)
Average population per household (person)	2.82	2.79
Per capita disposable income	29,732	43,193
Per capita basic expenditures (housing expenditure excluded)	24,126	26,126
Per capita residual income	5606	17,076
RI per household	15,808.92	47,616.93

4.2. RC and the Rental Affordability Index (RAI) of PRH in Nanjing

According to the stipulations of the Management Measures of Public Rental Housing in Nanjing and the Implementation Rules of the Parallel Operation of Public Rental Housing and Low-Rent Housing in Nanjing, PRH, which is funded (raised) and operated by the government, should be 40–60 square meters and priced by the government based on market rent levels at an appropriate level lower than that of ordinary commercial housing units in the same location and of the same type. In Nanjing, the government-approved monthly rent for government-funded PRH is 16 yuan per square meter [45]. According to this standard, the *RC* of a 40–60-square-meter PRH would be CNY 640–960 per month or CNY 7680–11,520 per year.

From the perspective of housing affordability, the low-income households in Nanjing can afford 40–60-square-meter PRH at an *RAI* between 0.48 and 0.72, while the corresponding affordability index for the lower-middle-income households is between 0.16 and 0.24. This implies that before including any transportation costs, 60-square-meter PRH may be easy to afford and the *RI* of these households would still exhibit a considerable surplus on average.

4.3. TC_{m+t} and Transportation Affordability Index (TAI) of the Low-Income and Lower-Middle-Income Households in Nanjing

4.3.1. Monetary Cost of Transportation (TC_m)

TC_m is divided into two travel modes: public transportation and private vehicles.

TC_m of public transportation: According to the current local regulations implemented since 30 March 2019, Nanjing's median cost of public transportation is CNY 5 per person per one-way trip and 1.87 persons are employed per household (according to the official data of the Statistical Yearbook of Nanjing). As such, the TC_m of public transportation for commuting purposes per household is approximately CNY 411.4 per month.

TC_m of private vehicles: This research focuses on low-income and lower-middle-income households, by which it is assumed that for any vehicle purchase, an economical car would be selected (this is also confirmed by the Nanjing Traffic Trip Survey data). The current purchase price for a representative vehicle is approximately CNY 100,000 (the price of an economical car in the Chinese market). Additionally, the annual insurance premium is estimated at CNY 4000–5000 and the fuel

consumption per hundred kilometers is 8 L. Generally, Nanjing employers provide parking options to their employees and the parking fees start at approximately CNY 900–1000 per year, much lower than the market price. Based on these data, the TC_m of private vehicle commuting in Nanjing is approximately CNY 1362 per month per person and CNY 2547 per month per household.

In summary, the annual household TC_m values for the public transportation and private vehicle commuting modes are CNY 4936 and 30,564, respectively.

4.3.2. Transportation Time Cost (TC_t)

The data for the 282 transportation communities with valid data were obtained from the Traffic Survey as the source objects and their accessibility for the two travel modes of public transportation and private vehicles was calculated. Using the Grid Data Statistics function in ArcGIS, the average time from each source object to all other transportation communities was determined, producing 564 datasets. The results reveal that the average one-day commuting time for Nanjing residents is 48 min via public transportation and 45 min via private vehicles (Figure 4).

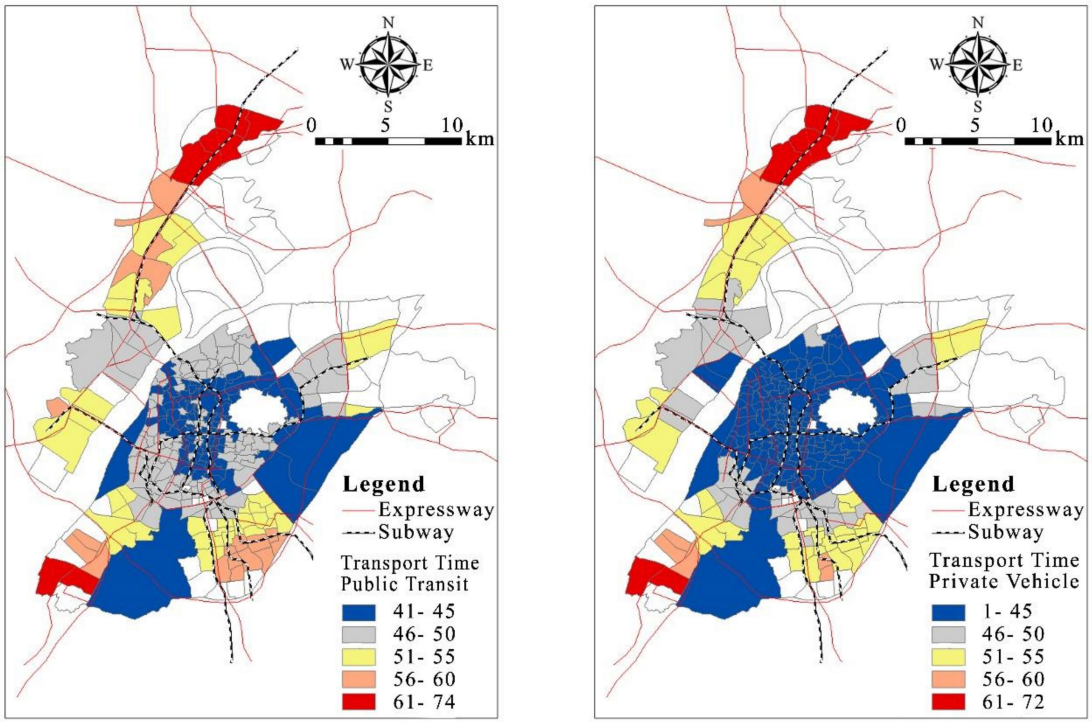

Figure 4. Nanjing residents' one-day commuting time with public transportation (**left**) and private vehicles (**right**).

As the time cost of waiting and transferring under the public transport mode was not considered in the accessibility analysis, to more reasonably calculate the actual commuting time costs for residents, a 5 min wait and transfer time was considered in the calculation when converting the public transportation time cost into its monetary equivalent. As such, the average commuting time of residents with public transportation is 53 min and the average commuting time with private vehicles remains 45 min.

Based on the per capita disposable income of the low-income and lower-middle-income residents in Nanjing in 2019, the transportation time cost was estimated as its monetary equivalent. Informing this calculation were the per capita hourly wages of the low-income and lower-middle-income residents, which were CNY 14.07 and 20.45, respectively (according to the official data of the Statistical Yearbook of Nanjing, 1.87 persons were employed per household in Nanjing in 2019). The resulting annual TC_t values for the four different groups of households in terms of income and travel mode—low-income households using public transportation, low-income households using private vehicles, middle-income

households using public transportation and middle-income households using private vehicles—are CNY 4363, 3705, 6343 and 5385, respectively.

4.3.3. TC_{m+t} and Transportation Affordability Index (*TAI*)

According to the two control variables, income (low-income and lower-middle-income households) and travel mode (public transportation or private vehicles), four sets of index data on TC_{m+t} and the traffic affordability index were obtained (Table 3).

Table 3. Transport affordability index (*TAI*) of PRH in Nanjing.

Household Classification	Travel Mode	TC_t (CNY)	TC_m (CNY)	TC_{m+t} (CNY)	*TAI*
Low-income Households	Public Transportation	4363	4936	9299	0.59
	Private Vehicles	3705	30,564	34,269	2.16
Lower-Middle-income Households	Public Transportation	6343	4936	10,979	0.42
	Private Vehicles	5385	30,564	35,949	0.75

Regarding low-income households, if they choose to commute by public transportation, the annual comprehensive transportation burden is approximately CNY 9299, exceeding the average estimated PRH rental house burden of CNY 7680. If they instead choose to commute by private vehicles, the annual transportation cost is approximately CNY 34,269. Notably, compared to the average household RI of CNY 15,808, the transportation burden for private vehicles alone would be unbearable.

For the lower-middle-income households, the *TAI* is 0.42, which is below 0.5 and 0.75 and the commuting choice of either public transportation or private vehicles appears affordable in relation to the estimated average RI of these households.

4.4. R&TAI of the PRH System-Targeted Groups in Nanjing

According to the classification of the low-income and lower-middle-income households, the assumed 40–60-square-meter PRH options and the possibility of commuting by either public transportation or private vehicles, the affordability indices under the eight possible scenarios can be calculated and compared (Table 4).

Table 4. *R&TAI* of the PRH system in Nanjing under the eight scenarios.

Income Classification	Travel Mode	*RI* (CNY)	$RC + TC_{m+t}$ (CNY)	*R&TAI*
Low-income households	Public transportation	15,808.92	16,979 (40 m^2 + public transportation)	1.07
			20,819 (60 m^2 + public transportation)	1.32
	Private vehicles		41,949 (40 m^2 + private vehicles)	2.65
			45,789 (60 m^2 + public vehicles)	2.89
Lower-middle-income households	Public transportation	47,616.93	18,659 (40 m^2 + public transportation)	0.39
			22,499 (60 m^2 + public transportation)	0.47
	Private vehicles		43,629 (40 m^2 + private vehicles)	0.91
			47,469 (60 m^2 + public vehicles)	0.47

By including the transportation cost data, the final combined affordability results indicate important findings. Most notably, the data indicate that if a typical low-income Nanjing household chooses the

40-square-meter PRH option, its *R&TAI* under the public transportation-based commuting scenario is 1.07, which already slightly exceeds the previously defined unbearable standard of unaffordability. If the same household either chooses the 60-square-meter PRH option or commutes with private vehicles, its *R&TAI* is either 1.32 or 2.65, respectively, indicating that the household would obviously be overburdened. In other words, a low-income household, at best, could most likely only bear the scenario involving the 40-square-meter PRH option and commuting by public transportation; it clearly could not afford the 60-square-meter PRH option or commuting with private vehicles.

By contrast, the situation of typical lower-middle-income households appears to be much better. If they choose the 60 square-meter PRH option and rely on public transportation, the *R&TAI* is only 0.47, indicating that the burden is not very heavy. The same households could also choose to commute by private vehicles and likely experience a certain degree of financial pressure but with an *R&TAI* of 0.99, the burden would probably remain bearable. However, these households would be left without any surplus income.

5. Discussion and Limitations

If only rental housing expenditures are considered, the study's results reveal that the rental pricing of the PRH system set by Chinese city managers appears to be reasonable, implying that the cost of renting itself is not the main factor influencing the sustainable development of the PRH system. The Nanjing case study herein demonstrates that after excluding basic living expenses, the *RI* of low-income households is CNY 15,808 and that of lower-middle-income households is CNY 47,616. Without considering the transportation costs of the residents' commutes to work, the *RC* of the lower-income households in Nanjing is between CNY 7680 and 11,520 and the *RAI* is between 0.16 and 0.72, so a typical household should easily be able to afford the 60-square-meter PRH option. As the calculated average number of residents per household in Nanjing was 2.83 in 2019, the per capita housing area is approximately 21 square meters. This meets the well-off living standard set by the Chinese government and the data indicate that the *RI* of these households would still result in a surplus.

While we focused on the combined affordability for the low-income groups, placing more emphasis on their associated transportation costs, the results of this study reveal that the combined cost burdens on the low-income households are very high, with the average *R&TAI* ranging from 1.07 to 2.89 and these households could probably only afford the 40-square-meter PRH option, even while relying on public transportation for all their commuting needs. This indicates that when considering the city's spatial layout and transportation costs, the living quality of a typical low-income household in Nanjing exhibits a downward trend. In this case, the per capita housing area would be approximately 14 square meters and such a household would find it difficult to maintain any *RI* surplus with which to expand their consumption beyond basic needs. Choosing the 60-square-meter PRH option or the private vehicle commuting mode would lead to household poverty. Rising transportation costs have reduced affordability for the low-income residents and households. From this perspective, the PRH policy has not truly alleviated the comprehensive burden on low-income households.

From the point of view of spatial layout optimization, improving accessibility could help to greatly reduce the transportation costs. Therefore, when formulating policies related to PRH and other indemnificatory housing systems, the government should not only pay attention to pricing but also pay more attention to spatial layout optimization and improving the accessibility of transportation around such housing systems. On the one hand, it is recommended that the government establish a master construction plan when executing new indemnificatory housing projects that includes planning the construction of supporting infrastructure nearby and selecting areas with high transportation accessibility, to avoid or gradually reduce the emergence of areas with a high comprehensive burden due to associated transportation costs. On the other hand, according to the comparative results for the housing and transportation burdens, the Transportation Bureau and related departments could also adjust and optimize the current construction planning for urban transportation infrastructure to

improve its accessibility for the outer areas of large cities or increase mixed living and working areas to enhance the comprehensive affordability for residents and households.

From the perspective of the residents' housing choices, it is strongly suggested that when designing housing plans, households should improve their consumption and risk awareness and reasonably consider their renting and house purchasing options, as well as their spatial locations. With the continuous progress of urbanization, different Chinese cities have adopted polycentric or single-center development models to expand their urban space and enhance the population-bearing capacity of their urban areas. Regarding urban commuters, both direct monetary costs and transportation time costs are increasing. As such, when formulating housing plans, residents will often need to consider trade-offs between their housing costs (purchase or rental prices) and transportation costs, especially those of low- and middle-income households, as they possess more-limited total disposable income. It is also necessary to comprehensively consider factors such as the actual needs and expectations of families, changes in household income levels, the spatial distribution of the different housing types and comprehensive burdens with the different commuting modes. Only through such a comprehensive approach can families choose the most appropriate housing plan, best reduce their comprehensive burden and improve their quality of life.

This paper attempted to develop a research model and examine new methods by applying the study of comprehensive affordability to the Chinese PRH system and selected a representative city for a meaningful empirical study. The research has been fruitful. However, certain limitations remain in the current research. First, this study only focuses on low-income residents and does not consider all types of residents. Second, the methods and models in this study could be further extended to all types of cities. In the future, our research team will continue this line of study in at least three aspects. First, in terms of the research depth, the study subjects should be expanded to include more types. Research on comprehensive affordability for low-income and lower-middle-income resident households in Nanjing should be extended to different types of urban residents and households, such as newly employed university graduates, rural migrant workers and start-up entrepreneurs, to analyze their different social stratification characteristics and examine their respective comprehensive affordability conditions. University graduates and start-up entrepreneurs are sources of innovation and vitality in a city and migrant workers are an important source of labor in cities. They remain in a state of financial hardship for a certain period of time when beginning to work, starting a business or just arriving in a city. In China, they are referred to as the social sandwich layer. Research on affordability for this urban sandwich class could provide a more detailed basis for city managers to develop rational housing security policies, satisfy the needs of residents in different social strata and provide appropriate indemnificatory housing options to all people experiencing various economic difficulties. This may be the key to effectively enhancing a city's attraction of talent and promoting the sustainable development of the economy and society. Housing affordability is a major factor for the mobility of talent [46–48]. This will probably be the most important direction for future research in this field. Second, in terms of the breadth of the study, we should continue to expand the number and type of sample cities. Beijing, Shanghai, Guangzhou, Shenzhen and other megacities should be included in the scope of the survey, as should medium-sized cities such as Yangzhou, Hefei and Zhengzhou. Influencing factors at deeper levels may be uncovered through the comparison of the different types of cities. Third, we also aim to continuously track the changes in the combined *R&TAI* of the low-income households in a city for many years to monitor the effectiveness of the PRH system and other policies to reform the affordable housing system. These studies are challenging, interesting and expected to be further strengthened in the future.

6. Conclusions

With the deepening reform of the Chinese housing security system and progress of urbanization, certain problems and deficiencies in the implementation of indemnificatory and low-rent housing policies have become increasingly visible, such as rent seeking, the unfair distribution of housing

resources, limitations on household registration and threshold discrimination. To help resolve these problems, since 2010, certain cities across China have begun to reform the PRH system. In 2012, the Chinese government promulgated the Measures for the Management of Public Rental Housing, which attempted to integrate indemnificatory housing, low-rent housing and PRH systems into a unified PRH management framework. Reform was gradually enacted throughout China via the three types of affordable-housing-merger-policy program. As such, renting, rather than selling, via the PRH system has become the core element of the Chinese housing security system.

And in practice, the management of PRH has been faced with a series of problems [49]. What is the affordability for residents under the PRH system? To what extent does the PRH system alleviate household residential stress and what problems does the PRH system encounter in the process of implementation that may prevent it from sustainably playing a positive role? This paper aimed to address these questions through quantitative and empirical research and the research concept of combined affordability was applied to the PRH system.

The placement of lower-cost housing in areas located far from job centers, remote suburbs or new towns may not represent a truly affordable housing solution. With the deepening reform of housing and land systems and the continued expansion of the urban space, due to the phenomenon of paid land use and land rent, housing (especially indemnificatory housing) in many cities across China—especially megacities such as Beijing, Shanghai, Nanjing and Guangzhou—continues to be planned and constructed along the urban fringes. Hence, people move to the suburbs. The general public facilities in these areas are not ideal and the costs of transportation to most central workplaces are relatively high. In fact, the trend of the suburbanization of the housing supply exerts the greatest impact on the low-income class in a city, who are the most profoundly affected by the consequent increase in costs. The lower the affordability for a low-income household, the more likely it is to choose low-cost housing, which is often accompanied by increased commuting distances and transportation costs. In many cases, low- and moderately low-income groups choose lower-cost housing but their resulting transportation costs may be much higher, even exceeding their housing costs, which results in a high financial burden. The continuous expansion of modern cities and distance between residents' workplaces and homes, the unreasonable spatial layout of indemnificatory housing and the resulting increase in associated transportation costs not only greatly impacts comprehensive housing affordability for urban low-income groups but also impacts the sustainable development of the PRH system itself; the spatial layout and transportation factors of the PRH and other indemnificatory housing systems will become the main factors influencing the ability of these systems to play a sustainable, positive role.

Furthermore, our results also demonstrate that only providing living spaces to low-income groups (such as PRH) does not reduce or eliminate the differences between the various social strata. According to our study, public transportation is vital for low-income groups due to their limited family surplus income; they heavily depend on it and have no other choices. Therefore, their transportation costs account for a large or even dominant proportion of their comprehensive expenses, thus aggravating the comprehensive burden on these groups; these families are left without any surplus income and either decrease their consumption of essentials or accrue debt. Hence, the social strata of these groups and their descendants become gradually solidified, which is obviously not conducive to the sustainable development of society. City managers should consider these factors when formulating urban development policies, promoting the fair use of urban space elements, balancing the indemnificatory housing supply [27] and ensuring true affordability [50].

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