



Study on Simulation of Nanjing Housing Sandwich Class Scale Based on System Dynamics

Xianghua Wu and Yaosheng Hu^(✉)

School of Economics and Management, Nanjing Tech University, Nanjing 211816, Jiangsu, China

hys513wzds@163.com

Abstract. With the failure of the housing market, the scale of urban housing sandwich class grows rapidly. They are residents who cannot afford commercial housing in the city, but whose income exceeds the local security line. Based on the theory of adequate housing rights, this paper proposes a measurement method for the scale of urban housing sandwich class. Combined with econometrics, the system dynamics model of the housing sandwich class scale in Nanjing was constructed. As the basis for parameter value of the model, python and MATLAB was used to crawl relevant data and fit the distribution. According to the results of the simulation, this paper analyses the change trend of the scale of the housing sandwich class in Nanjing under different policy regulation experiments. The study found that the scale of the sandwich class of housing in Nanjing is at a higher level and has a trend of further expansion. It will help to reduce the scale of sandwich housing class by strengthening the regulation of housing market prices, raising the income line of housing security, and increasing the supply of affordable housing. Meanwhile, the development of urban transportation and the reduction of commuting costs will help alleviate the housing problems of the sandwich class.

Keywords: Housing sandwich class · Housing security · Time series regression model · System dynamics model

1 Introduction

With the development of new urbanization in the past decade, the price of commercial housing in China's first and second tier cities has risen too fast, and the growth rate of urban residents' income has lagged behind the growth rate of housing prices for a long time. The contradiction between the rapidly growing demand for housing security and the inadequate development of housing security in China has become increasingly prominent [1–3]. This motivated the emergence of sandwich groups, whose affordability is insufficient to purchase commercial housing, but their income exceeds the standard line of security. Due to the slow development of the leasing market in China, there are problems such as nonstandard management and different rights to lease and sell, the sandwich class housing problem cannot be simply handled through leasing market or

leasing guarantee [4], and it is of great significance to effectively solve the sandwich class housing problem.

The housing problem of sandwich class is a complex system problem involving the operation of real estate market, urban economic development and housing security mechanism, which is suitable for in-depth research using system dynamics theory and methods. Based on the theory of housing market failure and the theory of adequate housing rights, this paper proposes a measurement method for the scale of the housing sandwich class. Combining the theories and methods of system dynamics and econometrics, the SD model of the housing sandwich class scale in Nanjing is constructed to measure the scale of the housing sandwich class group in Nanjing and forecast its changing trend, which providing guidance for reducing the scale of urban housing sandwich class and alleviating the housing problem of sandwich class.

2 Measurement Method

2.1 Theoretical Basis

This paper is based on the theory of housing market failure and the theory of the right to adequate housing. The rapid growth of urban housing prices and the imperfect housing security system have led to the inability to effectively allocate market resources, resulting in market disequilibrium. However, the housing market price and housing security directly affect the scale of urban housing sandwich group, so the most direct manifestation of market failure is the existence of sandwich group.

The right to adequate housing means that everyone has the right to an affordable standard of living, including adequate housing for himself and his family, and should be able to constantly improve living conditions. This requires that the affordability of housing and housing related personal or family costs should be kept at a certain level, that is, the percentage of housing related costs should be roughly commensurate with the income level [5]. Therefore, we assume that the expenditure required to enjoy a certain level of housing is just consistent with the expenditure for housing consumption of a certain group, that is, the housing price corresponds to their income.

2.2 Measurement Model

According to the definition of the housing sandwich class, we regards the people whose income level exceeds the local housing security standard but cannot reach the threshold price as the housing sandwich class, and the scale of the housing sandwich class is expressed by the proportion of the housing sandwich class group in the total urban population. The threshold house price refers to the lowest threshold for purchasing a house within the reasonable commuting range of the city. First, this paper establishes the relationship between housing price and residents' income, and transforms the range of housing price into the range of income level. Formula (1) is the calculation formula of housing sandwich class scale [6, 7].

$$PSC_t = \int_{2222_{p_t^0}}^{2222_{p_t^*}} f(x)dx \quad (1)$$

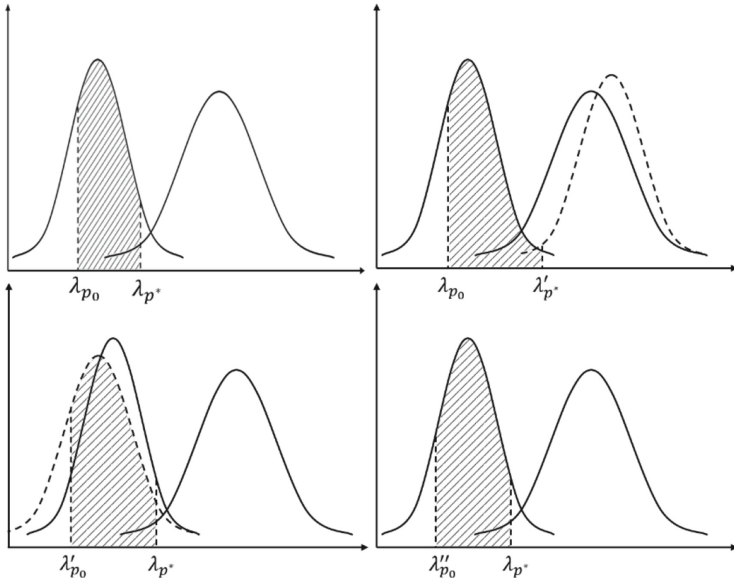


Fig. 1. Theoretical model of housing sandwich scale

In Formula (1), $f(x)$ is the probability density curve of residents' disposable income distribution in period t . $\lambda_{p_t^0}$ is the income line of housing security access announced by the government in period t . $\lambda_{p_t^*}$ is the income level corresponding to the threshold house price in period t . Formula (2) is the calculation formula of $\lambda_{p_t^*}$.

$$2222_{p_t^*} = \frac{p_t^* \times S_t \times m_t \times r_t \times (1+r_t)^n}{[(1+r_t)^n - 1] \times c_t} \tag{2}$$

In Formula (2), p_t^* is the threshold housing price level within the reasonable commuting range of the city, which is represented by the fifth percentile housing price of the sample in the region. S_t is the per capita housing area in period t . m_t is housing loan amount, r_t is housing loan interest rate, n is term of housing loan, c_t is proportion of housing consumption.

The shaded part in Fig. 1 indicates the scale of the housing sandwich class.

3 Data Selection and Test

Through academic literature research and summary, we found that the factors affecting the scale of the sandwich class of housing involve the operation of the housing market, urban economic development and housing security level. Therefore, this paper selects the time series data of Nanjing Commercial Housing Price (CHP), Average Floor Price (AFP), Housing Cost (HC), Real Estate Development Investment (REDI), Residential Development Investment (RDI), Permanent Residents (PR), Urbanization Rate (UR), Per Capita Housing Area (PCHA), GDP, Total Financial Revenue (TFR), Per Capita Financial Revenue (PCFR), Per Capita Disposable Income (PCDI) and Gini coefficient

Table 1. Unit root test results

VAR	order	ADF value	5% level significance	P value	Conclusion	VAR	order	ADF value	5% level significance	P value	Conclusion
CHP	1	-7.298001	-3.029970	0.0000	I(1)	CHPQ	0	-6.791356	-3.029970	0.0000	I(0)
AFP	1	-3.842417	-3.791172	0.0462	I(1)	AFPQ	0	-3.815822	-1.962813	0.0008	I(0)
HC	1	-10.98531	-3.029970	0.0000	I(1)	HCQ	0	-8.315174	-3.029970	0.0000	I(0)
REDI	1	-4.079920	-3.690814	0.0248	I(1)	REDIQ	0	-4.293617	-3.673616	0.0158	I(0)
RDI	2	-4.714096	-1.961409	0.0001	I(2)	RDIQ	0	-4.764222	-3.673616	0.0064	I(0)
RP	2	-5.134664	-1.962813	0.0000	I(2)	RPQ	1	-5.095911	-1.962813	0.0000	I(1)
UR	0	-16.80024	-3.690814	0.0001	I(0)	URQ	0	-2.002297	-1.966270	0.0465	I(0)
PCHA	1	-4.767898	-3.029970	0.0014	I(1)	PCHAQ	0	-5.151966	-3.673616	0.0031	I(0)
GDP	2	-5.038740	-3.040391	0.0009	I(2)	GDPQ	1	-4.953814	-1.961409	0.0001	I(1)
TFR	2	-3.123304	-1.962813	0.0039	I(2)	TFRQ	1	-4.378646	-1.962813	0.0002	I(1)
PCFR	1	-4.053499	-3.690814	0.0260	I(1)	PCFRQ	0	-3.750282	-3.690814	0.0450	I(0)
PCDI	2	-4.370492	-3.040391	0.0350	I(2)	PCDIQ	1	-5.489519	-1.961409	0.0000	I(1)
GC	1	-4.840937	-3.065585	0.0017	I(1)	GCQ	0	-4.415488	-1.964418	0.0002	I(0)

(GC) from 2000 to 2020. The above data are from Nanjing Statistical Yearbook and China Real Estate Statistical Yearbook.

According to formula $XQ_t = \frac{X_t - X_{t-1}}{X_{t-1}}$, this paper calculates the change rate of the above time series data to obtain their change rate series. Then we utilize Eviews12 to test the unit root of each time series and its change rate series to verify their stationarity. The unit root test results are shown in Table 1.

4 Model Building

4.1 Time Series Regression Prediction Model

According to the Akaike information criterion, we use the method of backward stepwise regression to build the autoregressive distributed lag model through Eviews12. The specific approach is that we use all possible variables and lag orders to model, and then continuously eliminate the most mismatched variables. By repeating operations, we can obtain the model with the lowest AIC value, that is, the model with the least free parameters that can best explain the data [8]. Formula (3) and Formula (4) are examples of commodity prices and per capita income.

$$\begin{aligned} \Delta\text{CHP}_t = & 100.36 + 0.46589\Delta\text{AFP}_t + 2.6357\Delta\text{HC}_t + \varepsilon_{1t} \\ & (t) \quad (0.48) \quad (6.49) \quad (10.49) \end{aligned} \tag{3}$$

$R^2=0.90 \quad DW=2.00 \quad AIC=16.32$

and

$$\begin{aligned} \text{PCDI}_t = & 1861.753 + 1.4171\text{PCDI}_{t-1} - 0.6597\text{PCDI}_{t-2} + 4.8273\text{TFR}_t + \varepsilon_{2t} \\ & (t) \quad (3.60) \quad (6.10) \quad (-2.54) \quad (2.42) \end{aligned} \tag{4}$$

$R^2=0.99 \quad DW=1.94 \quad AIC=16.09$

Table 2. Unit Root Test Results of Residual Sequence

Variable	T-test statistics	5% critical value	P value	Conclusion
ε_{1t}	-3.8723	-3.0522	0.0103	I(0)
ε_{2t}	-4.7371	-3.0404	0.0017	I(0)

We test the unit root of the above residual sequence ε_{1t} and ε_{2t} . The inspection results are shown in Table 2. We found that the t-test statistics are less than the 5% critical value, so it rejects the original hypothesis at least at the 95% confidence level. Therefore, ε_{1t} and ε_{2t} are integration of order zero. This shows that there is a cointegration relationship between the commodity housing price, average floor price and housing cost. And there is a cointegration relationship between per capita disposable income and total financial income.

4.2 System Dynamics Model

According to the above time series regression relationship, we make use of the software Vensim to build a system dynamics model of the scale of the housing sandwich class in Nanjing. The model is shown in Fig. 2.

All variable information of model is shown in Table 3.

- (1) In order to determine the value of model variable parameters, python computer network crawler technology is used to achieve the housing transaction data of Nanjing

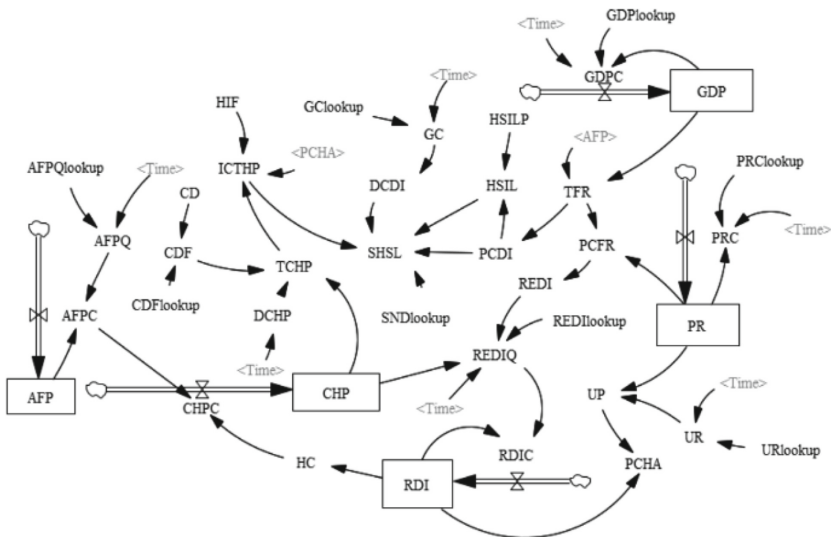


Fig. 2. SD Model of the Scale of Housing Sandwich Class

Table 3. SD Model Variable Information

variable	Code	Type	variable	Code	Type
Commercial Housing Price	CHP	level	Per Capita Housing Area	PCHA	auxiliary
Residential Development Investment	RDI	level	Threshold Commercial Housing Price	TCHP	auxiliary
Permanent Residents	PR	level	Distribution Coefficient of CHP	DCHP	auxiliary
Average Floor Price	AFP	level	Commuter Distance Factor	CDF	auxiliary
GDP	GDP	level	Commuter Distance	CD	auxiliary
Change of CHP	CHPC	rate	Income Corresponding to Threshold House Price	ICTHP	auxiliary
Change of RDI	RDIC	rate	Housing loan Factor	HIF	auxiliary
Change of PR	PRC	rate	Distribution Coefficient of PCDI	DCDI	auxiliary
Change of AFP	AFPC	rate	Gini Coefficient	GC	auxiliary
Change of GDP	GDPC	rate	Housing Security Income Line	HSIL	auxiliary
Scale of Housing Sandwich Class	SHSL	auxiliary	Housing Security Income Line Proportion	HSILP	auxiliary
Housing Cost	HC	auxiliary	Standard Normal Distribution Table Function	SNDlookup	lookup
Total Financial Revenue	TFR	auxiliary	GDP Table Function	GDPllookup	lookup
Per Capita Financial Revenue	PCFR	auxiliary	Table Function of PRC	PRCllookup	lookup
Real Estate Development Investment	REDI	auxiliary	Table Function of UR	URlookup	lookup
Change rate of REDI	REDIQ	auxiliary	Table Function of CDF	CDFlookup	lookup

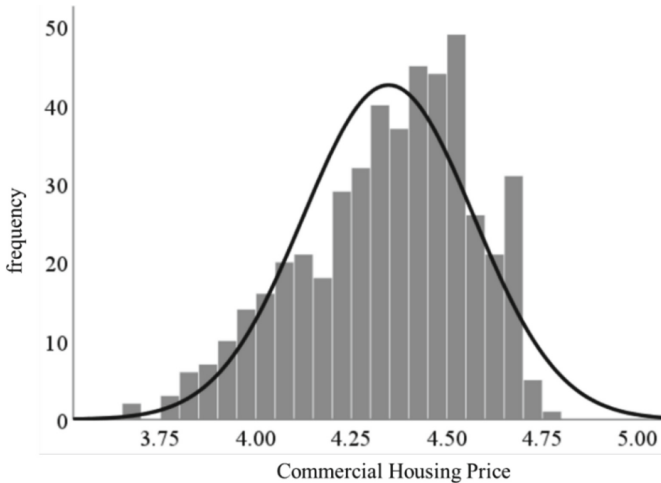
(continued)

Table 3. (continued)

variable	Code	Type	variable	Code	Type
Change rate of AFP	AFPQ	auxiliary	Table Function of AFPQ	AFPQlookup	lookup
Per Capita Disposable Income	PCDI	auxiliary	Table Function of GC	GClookup	lookup
Urban Population	UP	auxiliary	Table Function of REDI	REDIlookup	lookup
Urbanization Rate	UR	auxiliary			

and further analyze the distribution trend. We crawls the transaction data of 477 commercial residential buildings in Nanjing Anjuke website in 2020. After logarithmic processing, the data conforms to the normal distribution, with the mean value of 4.35, standard deviation of 0.223, skewness and kurtosis of -0.526 and -0.338 respectively. The price distribution is shown in Fig. 3. Therefore, the standard deviation coefficient of house price distribution calculated by the formula $V_{\sigma} = \frac{\sigma}{\mu}$ is 0.051. The fifth percentile price of all samples is calculated as 8402 RMB/m².

- (2) We perform the logarithmic processing on grouped resident income data, and then use MATLAB to fit the normal distribution of the processed data. The standard deviation of normal distribution obtained is in line with Gini coefficient = -1.672

**Fig. 3.** Normal distribution of market housing prices

+ 3.469GC'', R2 = 0.977. So, we get the functional relationship: $DCDI = -1.672 + 3.469*GC$.

- (3) In this paper, the logarithmic normal distribution is used as the fitting function of residents' income distribution, and the table lookup function is used to calculate the integral. Some functional relations and constant values are given below: $SHSL = SNDlookup((LOG(ICTHP,10) - (LOG(PCDI/12,10) - 0.5*DCDI*DCDI))/DCDI) - SNDlookup((LOG(HSIL,10) - (LOG(PCDI/12,10) - 0.5*DCDI*DCDI))/DCDI)$.
- (4) According to formula 2, we can easily know that: $ICTHP = TCHP*PCHA*HIF$. Based on the data published by the People's Bank of China, the latest benchmark annual interest rate of long-term loans is 4.90%, and the loan term is calculated by 30 years ($n = 360$). The housing consumption ratio is calculated on the 30% of international standard. Therefore, in our study, $c = 30%$, $m = 70%$. The housing loan factor is calculated by the formula $L = \frac{m \times r \times (1+r)^n}{[(1+r)^n - 1] \times c}$ as a constant of 0.0124.
- (5) $HSIL = (DELAY1(PCDI,1) * HSILP) / 12$. According to Document No. 91 issued by the General Office of Nanjing Municipal Government in 2013, the standard income line for housing security access in Nanjing is 80% at present of the disposable income of residents in the last year. Therefore, $HSILP = 0.8$.
- (6) Through the straight-line distance from each community to XinJiekou, we use SPSS software to calculate the house price of the fifth percentile within different distance ranges. Then, we take their ratio to the fifth percentile price of all samples as the distance factor. The calculation results are shown in Table 4.

After sorting and summarizing, we get the table function of commuting distance factor, and it is shown in Fig. 4.

According to the official data in 2021, the average commuting radius in Nanjing is 31 km at present, so the factor coefficient of commuting distance is 2.01.

Table 4. Distance factor coefficient

Commute Distance (Kilometers)	5th Percentile Price (yuan/m ²)	Factor Coefficient
15	22,209	2.64
20	21,368	2.54
25	19,702	2.34
30	16,973	2.02
35	16,040	1.90
40	14,780	1.75
45	12,545	1.49
50	11,134	1.32
55	9971	1.19

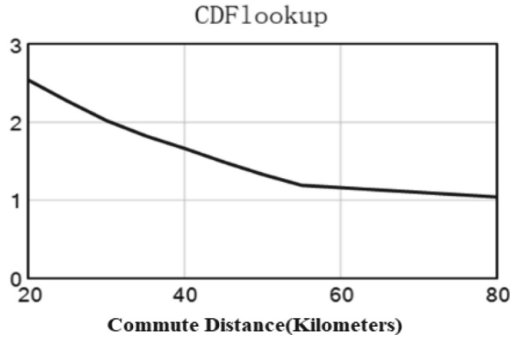


Fig. 4. Distance Factor Table Function

5 Model Simulation and Analysis

5.1 Model Simulation

The simulation time of the model is set as 2005–2030. The initial value of model simulation is the actual data of each level variable in 2005. And we use Vensim9.2 to realize model simulation by computer. Simulation results of main indicators are shown in Fig. 5 and Table 5.

The price of commercial housing and the income line of housing security access standards have a greater impact on the scale of urban housing sandwich class groups. On the basis of the original model, this paper adds the commodity housing price regulation variables and adjusts the proportion of the security line in the per capita income to conduct policy experiments (Table 6).

5.2 Analysis of Simulation Results

It can be seen from Fig. 4 that since 2005, the scale of Nanjing's housing sandwich class group has increased rapidly and remained further expansion trend, which reached a highest level of 0.52 in 2020. A large vacancy in housing security is shown. On the one hand, because of the growth rate of housing price in Nanjing has been faster than the growth rate of residents' income for a long time, residents' housing affordability is poor. On the other hand, there is a lack of mechanism for formulating the income line of housing security access linked to the housing market, resulting in the relative separation between housing security and the housing market. At the same time, with the development of urban economy and the improvement of people's living conditions, the per capita housing area has increased and the demand for housing security has further expanded.

It can be seen from the data in Table 5 that with the expansion of the commuting radius, the scale of the sandwich class in Nanjing and the income level corresponding to the threshold housing prices have decreased. Taking the radius expansion of 10 km as an example, the sandwich class index could decrease from 0.52 to 0.41 in 2020. The main reason is that with the expansion of the scope, the number of houses available for the

Table 5. Simulation Results of Housing Sandwich Floor Scale in Different Commuter Radius Ranges

Year	Scale of Housing Sandwich Class			Income Corresponding to Threshold House Price (yuan/month)		
	31 km	36 km	41 km	31 km	36 km	41 km
2020	0.5236	0.4707	0.4113	8796	7959	7234
2021	0.5123	0.4579	0.3974	9177	8304	7547
2022	0.524	0.4726	0.4146	9947	9001	8181
2023	0.5426	0.4956	0.4415	10,887	9851	8953
2024	0.5546	0.5103	0.4586	11,695	10,583	9618
2025	0.5631	0.5207	0.4707	12,466	11,280	10,252
2026	0.574	0.5338	0.4862	13,373	12,101	10,998
2027	0.5833	0.5455	0.5001	14,342	12,978	11,795
2028	0.5906	0.5544	0.5107	15,309	13,853	12,590
2029	0.5972	0.5627	0.5206	16,355	14,799	13,450
2030	0.6039	0.5712	0.5311	17,528	15,861	14,415

Table 6. Simulation results of housing sandwich scale under different regulatory policies

Year	Strengthening the Regulation of Housing Prices			No Change in Housing Price Regulation			Weakening housing price regulation		
	Strengthening safeguards	No Change	Weakening safeguards	Strengthening safeguards	No Change	Weakening safeguards	Strengthening safeguards	No Change	Weakening safeguards
2020	0.4790	0.5236	0.5685	0.4790	0.5236	0.5685	0.4790	0.5236	0.5685
2021	0.4672	0.5123	0.5576	0.4672	0.5123	0.5576	0.4672	0.5123	0.5576
2022	0.4678	0.5132	0.5589	0.4786	0.5240	0.5697	0.4805	0.5259	0.5716
2023	0.4720	0.5176	0.5635	0.4970	0.5426	0.5886	0.4968	0.5424	0.5884
2024	0.4780	0.5238	0.5699	0.5088	0.5546	0.6007	0.5132	0.5590	0.6051
2025	0.4842	0.5301	0.5762	0.5173	0.5631	0.6093	0.5284	0.5743	0.6204
2026	0.4899	0.5358	0.5820	0.5281	0.5740	0.6202	0.5416	0.5875	0.6337
2027	0.4947	0.5406	0.5869	0.5374	0.5833	0.6296	0.5534	0.5993	0.6456
2028	0.4989	0.5449	0.5912	0.5446	0.5906	0.6369	0.5638	0.6098	0.6561
2029	0.5025	0.5486	0.5949	0.5511	0.5972	0.6435	0.5728	0.6189	0.6652
2030	0.5058	0.5519	0.5982	0.5578	0.6039	0.6502	0.5804	0.6265	0.6728

sandwich class will increase, and the price level of houses farther from the city center will be lower.

Also, the data in Table 5 show that the income level corresponding to the threshold house price has also decreased from 8796 RMB/month to 7234 RMB/month, but it is still much higher than the average of 5629 RMB/month in this year. The situation reflects the reality that even though sandwich class groups choose to sacrifice their commuting time in exchange for higher housing affordability, their housing payments are still difficult.

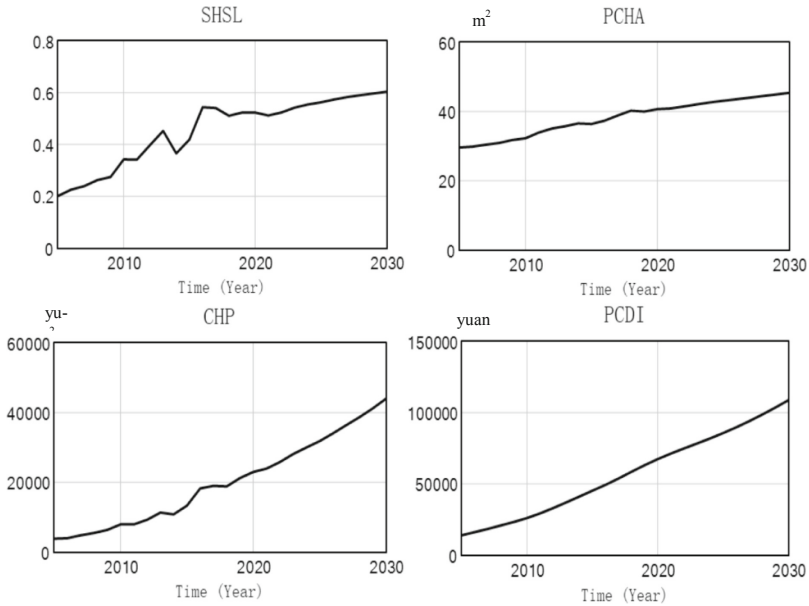


Fig. 5. Output Diagram of Main Indicators

According to the simulation results in Table 6, we found that strengthening the price regulation of commercial housing and increasing the proportion of housing security income line can effectively reduce the scale of the housing sandwich class group in Nanjing. If the proportion of housing market regulation and security line remains unchanged, the scale of sandwich class will increase from 0.52 in 2020 to 0.60 in 2030. Additionally, if the government strictly controls the housing price and increases the proportion of the security line simultaneously, the scale of the sandwich class will only increase from 0.48 to 0.51. And the continuous expansion can be basically controlled.

6 Conclusions

This paper proposed a method to measure the scale of urban housing sandwich group. The SD model of scale of Nanjing housing sandwich class was established for simulation research based on system dynamics and econometrics theory. The results showed that the scale of the housing sandwich class in Nanjing is at a higher level and has a trend of further expansion. The main factors affecting the scale of the housing sandwich class in Nanjing were the price of commercial housing, the distribution of housing prices, per capita disposable income and the level of housing security. In order to reduce the scale

of the sandwich group in Nanjing and solve the housing problem of the sandwich group, suggestions are as follows:

- (1) The government should strengthen the regulation of housing market price, improve the structure of residential land and housing supply, increase the supply of rigid demanded housing within the affordability of sandwich housing groups, and maintain the healthy and sound development of the real estate market.
- (2) The government should establish the mechanism for formulating the income line of housing security access, which is linked to residents' income, financial income and the housing market. In addition, adjusting the income line of housing security access flexibly according to the housing security gap to achieve coordinated development of housing security and the housing market.
- (3) For the housing sandwich class, the government can develop housing with common property rights within the reasonable commuting range of the city. And reasonably determining the scale of construction and fundraising, and property rights ratio. Then, strictly formulating the access and exit mechanism, so as to improve the housing payment ability of low- and middle-income families and strengthen the housing property rights guarantee.
- (4) Urban public transportation should be developed, urban public facilities should be perfected, and multi-center cities should be established to ease the commuting difficulties of sandwich class and improve the quality of life of sandwich class groups.

References

1. Kwong H. Housing for the middle-income group: sandwich class housing loan scheme (1993). HKU Theses Online (HKUTO), 1994.
2. Jie Chen. Housing Solutions for Urban Residents: Theory and International Experience. Shanghai: Shanghai University of Finance and Economics Press, 2009.
3. Jianqing He, Lifan Shu. Research on Housing Security of Urban Sandwich Layer Groups. *Price Theory and Practice*, 2011 (3): 39-40.
4. Xuefeng Liu. Simplifying the "sandwich layer" problem is a mistake in housing policy. *Shanghai Real Estate*, 2014 (01): 14-15.
5. Zhenyu Bao. *Zhaizi China: Historical Development and Contemporary Practice of Housing Right Theory*. Beijing: Social Science Literature Press, 2017.
6. Xianghua Wu, Minghui Ding. Research on the Sandwich Class Index of Housing -- Comparison Based on Typical Cities. *Building Economy*, 2021,42 (04): 88-92.
7. Xianghua Wu, Liting Zhang, Huizhu Wu. Research on the Sandwich Stratum in the Housing Rental Market -- Taking the pilot cities for leasing as an example. *Mathematical Practice and Understanding*, 2021,51 (15): 155-162.
8. Tiemei Gao. *Econometric Analysis Methods and Modeling*. Beijing: Tsinghua University Press, 2006.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

