
**Using the Granger Causality Test to Examine Whether Economic Policy
Uncertainty Has a Significant Impact on Social Housing Rents**

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Abstract

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Issues such as excessively high housing prices, a high vacancy rate, and insufficient transparency in the rental market are currently occurring in Taiwan’s housing market. Since 2011, the R.O.C. (Taiwan) government has promoted a policy of renting and not selling social housing, and through related plans, it has assisted socio-economically disadvantaged households to rent housing.

This study is based on the real options valuation model, assuming that the value of privately owned social housing follows a geometric Brownian motion. It proposes a related valuation model, conducts sensitivity analysis, and further employs the Granger causality test to examine whether economic policy uncertainty has a significant impact on rents in the social housing market.

This study also proposes investment strategy recommendations for social housing, along with corresponding methods for assessing trends in average price volatility (σ_s). Taking Taichung City as an example, when calculating the option premium (OP), since TEPU affects CPIR at the 10% significance level, the results of the Granger causality test between CPIR and TEPU can be used to assess the future trend of σ_s .

The valuation model developed in this research provides an objective and comprehensive framework for evaluating privately owned social housing, and the findings can serve as a reference for private enterprises when conducting social housing valuation.

Keywords: Social housing, Real option valuation model, Economic policy uncertainty, Granger causality test, Geometric Brownian motion

1. Introduction

Granger causality can decompose the relationships among variables into multiple independent regression equations to examine the “correlation” between the current value of one variable and the past values of other variables. This study uses Granger causality tests to explore whether economic policy uncertainty has a significant impact on rents in the social housing market.

Issues such as excessively high housing prices, a high vacancy rate, and insufficient transparency in the rental market are currently occurring in Taiwan’s housing market. Since 2011, the R.O.C. (Taiwan) government has promoted a policy of renting and not selling social housing, and through related plans, it has assisted socio-economically disadvantaged households to rent housing.(CPAMI, Construction and Planning Agency, Ministry of the Interior, R.O.C., 2018). The term “social housing” is a term introduced by European countries (Scanlon et al., 2014). Since the Japanese colonial period, the “Public Housing Plan” has been the main residential policy in Taiwan, with the government taking overall responsibility for planning and implementing national housing projects (Institute for Physical Planning & Information, 2012). Refer to Articles 3 and 4 of the “Housing Act” promulgated on January 11, 2017 in Taiwan, the term “social housing” refers to housing and necessary facilities built by the government or by the private sector with subsidies from the government that is primarily rented.

Refer to Articles 19 to 21 of the “Housing Act”, social housing may provided by the competent authorities or private organizations. With reference to the aforementioned regulations and relevant directives issued by Ministry of the Interior, R.O.C., the development of social housing in Taiwan can be carried out through diverse methods and channels, as illustrated in Figure 1. (Shieh & Su, 2021).

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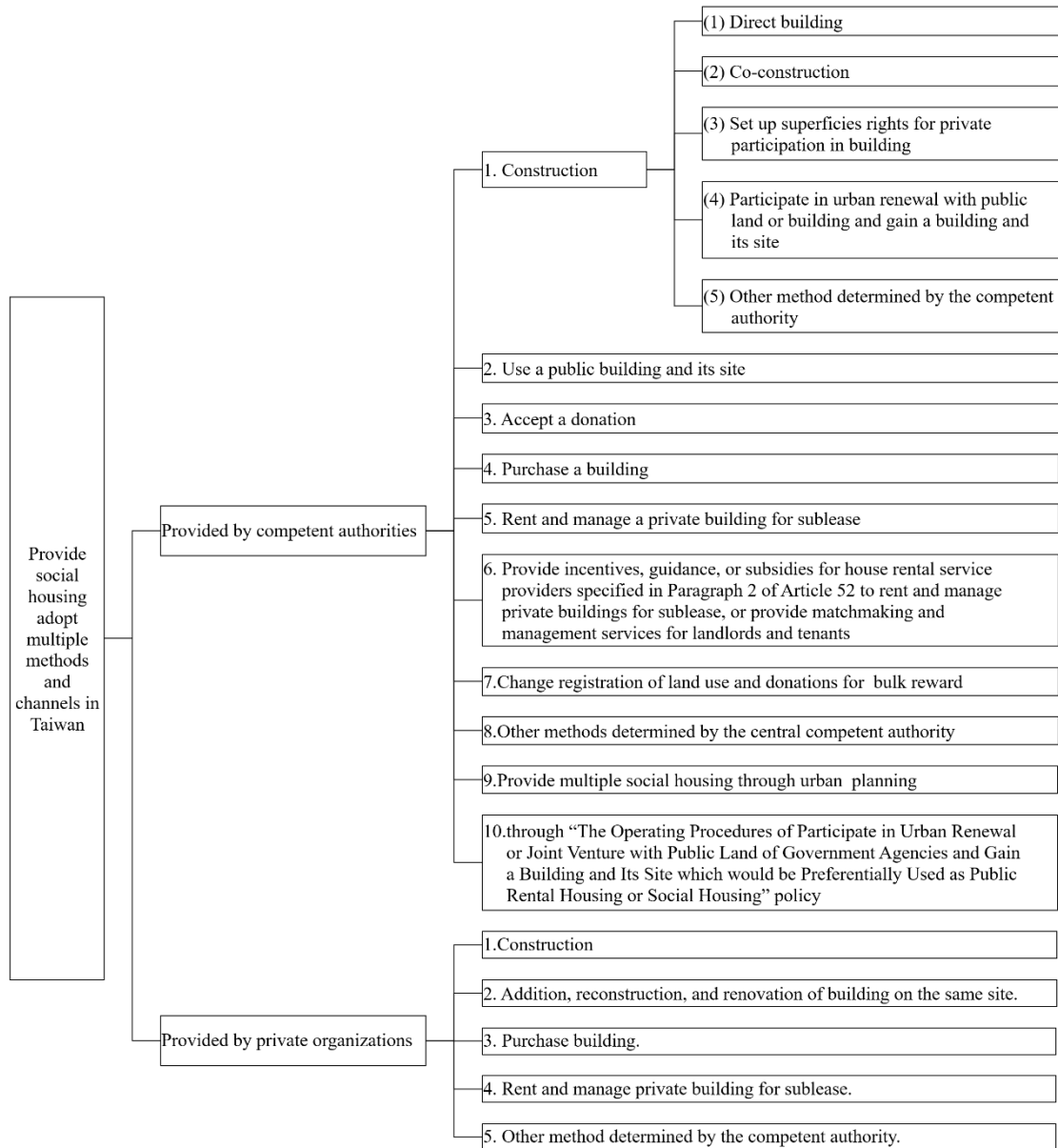


Fig. 1. Provide social housing adopt multiple methods and channels in Taiwan

2. Literature review

Due to various objectives like obtaining the private sector’s finance and expertise, allocating risks, improving service quality and lowering life-cycle cost (Abdul-Aziz & Jahn Kassim, 2011), the private sector has been adopted broadly to promote the provision of social housing. For example, there are currently about 378 social housing associations in the Netherlands, which manage 2.4 million social housing units. They own social housing ownership, and are responsible for construction, operation and management. The lands acquisition of those associations come from the government’s cheap rental land and are subject to considerable

control. By providing policy incentives and the establishment of residential legal entities by the third sector, the social housing is provided by the specialized agencies of residential legal entities (Taiwan Competitiveness Forum, 2015). That is, the government entrusts a private NGO or NPO, Dutch Housing Association, a non-profit third-party independent organization formed as a cooperative to develop, build, and manage (Shieh & Su, 2021; ABRI, Architecture and Building Research Institute, Ministry of the Interior, R.O.C., 2018).

According to Shieh & Su (2021), real options theory originated in 1977 with the groundbreaking idea of Stewart Myers that Black-Scholes financial option pricing model developed in 1973 can be applied to capital-budgeting, later it was proved by Folta & O'Brien (2004) and Borison (2005). Myers (1977) originally defined "real options" as: "opportunities to purchase real assets on possibly favourable terms"(Čirjevskis & Tatevosjans, 2015).

Refer to Li et al.(2014) and this study, Real option valuation model (ROV) has been utilized in a variety of real estate development decision, from planning to operations and from operations to abandonmen(Hui et al., 2010). Some studies apply ROV to predict land prices (Grovenstein et al., 2011; Shen & Pretorius, 2013) or rent of soil (Hsieh & Lin, 2016), and some scholars utilize ROV to value certain types of real estate development, such as recreational facilities (Leung & Hui, 2002), public housing upgrading (Ho et al., 2009), office construction (Fu & Jennen, 2009) and farm (Stokes, 2012).

According to Su (2023); Gerlach & Peng (2005), cointegration analysis and an error correction model were used to examine the relationship between bank lending and housing prices in Hong Kong. The empirical results show that housing prices have a significant impact on the total amount of bank lending in both the long run and the short run. However, the Granger causality analysis indicates that the total amount of bank lending does not Granger-cause housing prices. Su (2023) and Li (2022), previous literature examining how economic policy uncertainty is transmitted and how it affects the real estate market often employs the Granger causality test for analysis. El-Montasser et al., (2016) used the Granger causality test to investigate the causal relationship between real housing prices and economic policy uncertainty in seven developed countries—Canada, France, Germany, Italy, Spain, the United Kingdom, and the United States. Their empirical results indicate a bidirectional causal relationship between real housing prices and economic policy uncertainty.

Bouri, Gupta, Kyei, 與 Shivambu (2021) employed the quantile Granger causality test to examine whether returns and volatility in the U.S. real estate market are affected by economic policy uncertainty. The empirical findings show that the economic policy uncertainty index does indeed influence housing returns and volatility in the United States, exhibiting a unidirectional causal relationship.

Su (2023) and Que (2011), the Granger causality model is a type of time series Vector Autoregression (VAR). This testing model is based on the perspective of prediction, examining the "correlation" between the current value of a variable and the past values of

other variables, rather than representing true causality in macroeconomic theory.

Granger causality is as follows: suppose there are two variables, X and Y. When predicting Y, in addition to the past lagged values of Y itself, if incorporating past information from variable X reduces the prediction error of Y and improves its predictive accuracy, then X is said to “Granger-cause” Y. If X does not Granger-cause Y, then X does not help in predicting Y. If both variables exhibit Granger causality toward each other, a bidirectional feedback relationship exists. If neither variable Granger-causes the other, then the two variables are considered independent in terms of providing predictive information.

3. Scope and methodology

3.1 Taichung City's incentive measures for privately developed social housing, including financial subsidies and tax reductions

In Taichung City, social housing is currently developed exclusively by the competent authorities, and there have been no cases initiated by private developers. To achieve policy objectives, social housing may lack financial self-sufficiency; therefore, encouraging private sector participation requires the provision of proactive financial subsidy incentives. Only through these various forms of financial support and incentive design can the flexibility and efficiency of the private sector be mobilized to participate in the development of social housing, while still meeting policy goals such as increasing supply, protecting target groups, and offering rent concessions (Organization of Urban Re-s, R.O.C. , 2015).

According to Shieh & Su (2021), in order to reward private sector to provide social housing, Taiwan and Taichung City have also issued relevant incentives for private sector to provide social housing in terms of financial subsidies and tax relief. According to Articles 2 and 3 of the “Regulations on Preferential Treatment for Rent and Setting up Superficies for Private Organizations to Provide Social Housing by Using Non-public Use Publicly Owned Property”, relevant financial subsidy measures have been stipulated for the royalties of superficies, the rent for rent and setting up superficies, and the rent of public buildings. According to Article 4 of the “Taichung City Self-Government Ordinance for Providing Preferential Treatment on Social Housing Provision and the Houses Leased out by Public Welfare Landlords”, the relevant tax reduction and exemption measures have been established for the basis and scope of the reduction and exemption of land value tax and house tax during the provision of social housing. Related incentives (shown in Table 1) need to be considered in the model proposed in this study.

Table 1. Incentives for rewarding private sector to build social housing

| Item Number | Operating expenses or tax denomination | Basis | Ratio or tax rate | Deducted ratio |
|-------------|---|---|-------------------|--|
| 1 | Operating expenses | | | |
| 1-1 | Royalties of superficies | Assessed present value | 10% | 0% |
| 1-2 | Rent for rent and setting up superficies | | | |
| 1-2-1 | From the effective date of the contract to the period before the approved operation | Land area & declared value | More than 10% | 0% |
| 1-2-2 | During the operation period | Land area & Declared value & The ratio rented to economically or socially disadvantaged persons | More than 10% | Calculated according to the ratio rented to economically or socially disadvantaged persons |
| 1-3 | Rent of public buildings | | | |
| 1-3-1 | From the effective date of the contract to the period before the approved operation | Current value of the house | Less than 4.8% | 0% |
| 1-3-2 | During the operation period | Current value of the house & The ratio rented to economically or socially disadvantaged persons | Less than 4.8% | Calculated according to the ratio rented to economically or socially disadvantaged persons |
| 2 | Tax items | | Tax rate | |
| 2-1 | Land value tax | Land area & declared value | More than 10% | 80% |
| 2-2 | House tax | Current value of the house | Less than 4.8% | 20% |

3.2 NPV at decision making stage of the privately-owned social housing projects

With reference to Article 32 of the Regulations on Real Estate Appraisal, discounted cash flow (DCF) analysis is used to value projects, companies or assets, and the time value of money is calculated at the discount rate. The sum of all discounted cash flows each year is the net present value (NPV), can be calculated as:

$$NPV = \sum_{t=0}^n \frac{(CI_t - CO_t)}{(1+q)^t} \quad (1)$$

Here, t means time in unit of year; n means the life-span of the privately-owned social housing project; CI_t and CO_t means the cash inflow and cash outflow of the privately-owned social housing project at year t separately; q means the discount rate.

As for CI_t, its principal source is the rent income of social housing buildings, including social housing rental income, parking spaces rental income and other (shops and social welfare facilities of residential services for people with disabilities, kindergarten, etc.) rental income, which equals to the product of its total building area, average rent, average letting rate and operation period (need to deduct the annual idle period). The total building area is generally determined by the land area and maximum floor area ratio, can be determined by the calculation results of the preliminary plan of the case. With regard to the average rent, the law assumes 70% of that of similar private rented housing buildings nearby. In most cases, a certain quantity of other affiliated businesses (such as commercial buildings) will be allocated in social housing projects as a subsidy to improve the financial performance. With regard to the average letting rate, it can be estimated from comparison analysis with running social housing projects in the same city, or from the demand and supply situation of local social housing. As for the operation period of social housing buildings and other affiliated businesses (such as commercial buildings), generally, it is estimated that the construction period is 3 years and the operation period is 50 years (Shieh & Su, 2021; Taiwan Institute of Property Management, 2018; Dragonpolis Engineering Consulting, 2019).

As for CO_t, there are four main sources of a privately-owned social housing project, namely the purchase cost of land, capital expenditures (construction cost of buildings), operating expenditures and loan interest.

As for q, with reference to Article 43 of the “Regulations on Real Estate Appraisal”, the discount rate should be determined from a comprehensive review of the methods, including risk premium method, market extraction method, weighted average capital cost method, debt coverage ratio method, and effective gross income multiplier method. Internationally, in addition to the aforementioned methods, q can still be calculated by several quantitative methods, including Capital Asset-Pricing Model (CAPM), Multifactor Asset-Pricing Model (MAPT) and Arbitrage Pricing Theory (APT), or qualitatively set by management as a requirement for the firm, or as hurdle rate for specific projects (Mun, 2005).

3.3 ENPV at decision making stage of the privately-owned social housing projects

In the international literature on land development and public construction, there are three common options: a deferral option, an option to expand and an abandonment option (Chen et al., 2004). As regards real options which are applicable to real estate development, they may be summarized as a deferral option, an abandonment option, an option to expand/ contract, a switching option, a growth option and a compound option (Trigeorgis, 2005 : Guma, 2008).

Considering characters and management flexibilities of the proposed privately-owned social housing model, the private real estate developer generally has two real options at decision making stage, which are a deferral option and an abandonment option separately. As for the abandonment option, it is the last choice and will not be exercised in general conditions because of the irreversible investments, e.g. construction costs. So, the only considered real option is the deferral option (Shieh & Su, 2021; Li et al., 2014).

According to Shieh & Su (2021), multiple models and approaches are available for valuing option premium (OP), whilst Black-Scholes model is most widely used, because of its simplicity in process and accuracy in results. As explained before, deferral option is the principal real option of privately-owned social housing projects at decision making stage, and it should be excised at any time without affecting the progress of the construction, which is so short that the deferral option of privately owned social housing projects can be simplified as European style. As a result, the Black- Scholes model is applicable to privately-owned social housing projects. Furthermore, this basic model is modified by considering the value leakage, which derives from several reasons (e.g. possible construction accompanied cost increase as a result of inflation) in the deferral period.

Like Hui et al. (2011) demonstrated, before constructing the assessment model of option premium of privately-owned social housing projects, three assumptions should be made: ①the value of one privately-owned social housing project follows geometric Brownian motion, and its rate of return is normally distributed; ②the risk-free interest rate and property’s price volatility are known and constant throughout the period of development; ③the option is priced in a frictionless market. Then, if the value leakage is δ , the value S at time t (i.e. S_t) of one privately-owned social housing project varies according to a stochastic differential equation in the form of:

$$dS_t = (r_f - \delta)S_t dt + \sigma_s S_t dB_t \quad (2)$$

Here, r_f means risk-free interest rate; σ_s is the average volatility of social housing project rent; B_t is one-dimensional Brownian motion. Then, based on the risk-neutral assumption and Ito’s lemma (Chen, 2007), the stochastic differential equation of the privately-owned social housing project’s OP and its boundary condition can be written as:

$$\frac{\partial OP}{\partial t} = r_f OP - (r_f - \delta)S_t \frac{\partial OP}{\partial t} - \frac{1}{2} \sigma_s^2 S_t^2 \frac{\partial^2 OP}{\partial S_t^2} \quad (3-1)$$

$$OP(S_t, T) = \text{Max}[(S_t - C_t), 0] \quad (3-2)$$

Here, C_t is the investment cost of the privately-owned social housing project at time t . Solving the stochastic differential equation of Equation (3-1) & (3-2), it is found that:

$$OP_t = S_t e^{-\delta(T-t)} N(d_1) - C_t e^{-r_f(T-t)} N(d_2) \quad (4-1)$$

$$d_1 = \frac{\left[\ln\left(\frac{S_t}{C_t}\right) + \left(r_f - \delta + \frac{\sigma_s^2}{2}\right) \right]}{\sigma_s \sqrt{T-t}} \quad (4-2)$$

$$d_2 = \frac{\left[\ln\left(\frac{S_t}{C_t}\right) - \left(r_f - \delta + \frac{\sigma_s^2}{2}\right) \right]}{\sigma_s \sqrt{T-t}} = d_1 - \sigma_s \sqrt{T-t} \quad (4-3)$$

Here, T is the maturity time of the privately-owned social housing project's deferral option; $N(d_1)$ and $N(d_2)$ are cumulative probabilities of the variable smaller than d_1 and d_2 separately. The conventional NPV method has been repeatedly criticized for its disabilities in dealing with uncertainty, irreversibility and management flexibility, while these disabilities can be cured by ROV. However, as a broadly utilized decision making approach, the NPV method has many undeniable advantages (Chen, 2007). Trigeorgis (2005) put forward a new expanded NPV criterion to capture the additional value of managerial operating flexibility and other strategic interactions:

Expanded (or strategic) NPV(ENPV) = passive NPV + Option Premium (OP) (ROV, Flexibility value and Strategic value).

Based on such a model, it may now be justified to accept projects with negative NPV of expected cash flows (if this is offset by a larger option premium as a result of additional flexibility and strategic value), or delay investment with positive NPV until a later time when expanded NPV would be maximized under uncertainty (Trigeorgis, 2005). This model is adopted, optimized and exemplified in this study to value privately-owned social housing projects.

Since this study aims to value the privately-owned social housing project at decision making stage, t becomes 0 in Equation (4-1) ~ (4-3) combining Equation (1), the real option-based valuation model for the privately-owned social housing project at decision making stage can be written as:

$$ENPV = \sum_{t=0}^n \frac{(CI_t - CO_t)}{(1+i_c)^t} + S_0 e^{-\delta T} N(d_1) - C_0 e^{-r_f T} N(d_2) \quad (5-1)$$

$$d_1 = \frac{\left[\ln\left(\frac{S_0}{C_0}\right) + \left(r_f - \delta + \frac{\sigma_s^2}{2}\right) \right]}{\sigma_s \sqrt{T}} \quad (5-2)$$

$$d_2 = \frac{\left[\ln\left(\frac{S_0}{C_0}\right) - \left(r_f - \delta + \frac{\sigma_s^2}{2}\right) \right]}{\sigma_s \sqrt{T}} = d_1 - \sigma_s \sqrt{T} \quad (5-3)$$

3.4 The test content according to the Granger causality test

3.4.1 Taiwan Economic Policy Uncertainty Index

In this study, the variable for Economic policy uncertainty (EPU) is derived from the Taiwan EPU Index constructed by Huang et al. (2021), which follows the methodology of Baker et al. (2014, 2016) and EPU indices developed for other countries. The data source consists of online news articles from major newspapers spanning from May 1, 2003, to June 30, 2018. The sample period for the Taiwan EPU Index used in this study covers January 2004 to December 2017 (a total of 168 months, or 14 years), with monthly frequency.

In addition, for “privately owned social housing,” at the time when the social housing is newly completed, the rental price of newly built residential units is evaluated. The relevant index is the rental index compiled by the Directorate-General of Budget, Accounting and Statistics (Rental Index in the Consumer Price Index, CPI Rent).

Furthermore, since the data collection period for the Taiwan EPU Index spans from January 2004 to December 2017 (a total of 168 months, or 14 years), and the CPI Rent Index is updated on a monthly basis, this study aligns the sample period accordingly. Therefore, the sample period for the CPI Rent Index used in this study is also from January 2004 to December 2017 (a total of 168 months, or 14 years), with monthly frequency.

3.4.2 The definition of Variable

When examining whether economic policy uncertainty has a significant impact on social housing rents, this study takes the natural logarithm of the rental index compiled by the Directorate-General of Budget, Accounting and Statistics for period t (Rental Index $_t$ in the Consumer Price Index, CPI Rent), and denotes it as the consumer price rent index ($\ln \text{CPIR}_t$).

$$\text{Thus, } \ln \text{CPIR}_t = \ln(\text{Rental Index in the Consumer Price Index})_t \quad (6-1)$$

F

ollowing the approaches of Su (2023) and Li (2022), this study obtains the EPU indices for five Asian economies—China, Hong Kong, Japan, South Korea, and Singapore—from the website established by Baker et al. (2016). It then examines the impact of economic policy uncertainty on housing prices in each country. The EPU index of country i in period $t-1$ (EPU_{t-1}^i) is transformed by taking its natural logarithm to serve as the variable measuring economic policy uncertainty for each country ($\ln \text{EPU}_{t-1}^i$).

$$\text{Thus, } \ln \text{EPU}_{t-1}^i = \ln(i \text{ Country EPU Index of Period } t-1) = \ln(\text{EPU}_{t-1}^i) \quad (6-2)$$

When examining whether economic policy uncertainty has a significant impact on the amount of social housing rents, this study takes the natural logarithm of the Taiwan EPU index in period $t-1$ (TEPU_{t-1}) as the variable measuring Taiwan’s economic policy uncertainty ($\ln \text{TEPU}_{t-1}$).

$$\text{Thus, } \ln \text{TEPU}_{t-1}^i = \ln(\text{Taiwan EPU Index of Period } t-1) = \ln(\text{TEPU}_{t-1}^i) \quad (6-3)$$

3.4.3 Analysis steps

The data defined in the aforementioned variables are time series data. Following the approaches of Su (2023), Li (2022), Chen (2013), and Liu (2008), this study sequentially employs unit root tests, cointegration tests, and Granger causality tests for analysis. These methods are used to examine whether there exist leading and lagging relationships among the variables, as explained below.

3.4.3.1 Unit Root Test (This study adopts the ADF unit root test)

Time series data analysis generally involves two types of data characteristics: stationary and non-stationary series. If an external shock to a time series produces only a temporary effect that dissipates over time, allowing the series to return to its long-term mean level, then the probability distribution of the stochastic process does not change over time. In such cases, the mean, variance, and autocovariance are all finite constants, and the series is considered stationary.

In contrast, when a series is affected by an external shock that produces a persistent (permanent) impact, it exhibits a long-term memory characteristic, causing the data to gradually deviate from its mean. Such a series is referred to as a non-stationary time series and is characterized by the presence of a unit root.

If a time series must be differenced d times to achieve stationarity, it is called an “integrated of order d ” series, denoted as $I(d)$. If the series is already stationary without differencing, it is referred to as an “integrated of order zero” series, denoted as $I(0)$.

Methods for testing whether data are stationary originated from the Dickey-Fuller (DF) unit root test proposed by Fuller (1976) and Dickey & Fuller (1979), as well as the Augmented Dickey-Fuller (ADF) unit root test. The Augmented Dickey-Fuller (ADF) test proposed by Dickey & Fuller (1979) extends the original Dickey-Fuller (DF) test by incorporating lagged terms of the dependent variable on the right-hand side of the regression equation, in order to account for the data-generating process of lagged time series and eliminate autocorrelation in the residuals. This study adopts the widely used ADF test to conduct unit root testing.

Depending on whether the model includes an intercept term and a time trend term, the ADF unit root test can be classified into the following three models:

3.4.3.1.1 No intercept and no time trend term

$$\Delta y_t = \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \varepsilon_t$$

3.4.3.1.2 With an intercept term but no time trend term

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (7-2)$$

3.4.3.1.3 With an intercept term and a time trend term

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \delta t + \varepsilon_t \quad (7-3)$$

In Equations (7-1) to (7-3), Δ denotes the first difference, and y_t represents the index (variable) to be predicted. α is the intercept term, β is the autoregressive coefficient, and $\sum_{i=1}^n \gamma_i \Delta y_{t-i}$ represents the lagged terms of the dependent variable. Here, n is the optimal lag length that ensures ε_t follows white noise, δt represents the time trend, and ε_t is the error term, which is assumed to satisfy the white noise condition.

The hypotheses for the above three models are as follows:

$$H_0 : \beta = 0 \text{ (unit root exists)} \quad (8-1)$$

$$H_0 : \beta \neq 0 \text{ (no unit root)} \quad (8-2)$$

If the original series fails to reject the null hypothesis $H_0: \beta = 0$ (i.e., a unit root exists), it can be concluded that the series contains a unit root. In such a case, the series should be differenced repeatedly until it becomes stationary.

To correct for autocorrelation in the residuals and ensure that they follow a white noise process, appropriate adjustments are required. According to Yang (2009), white noise refers to a time series of random variables that satisfies specific statistical properties: a mean of zero, a constant variance, and zero autocovariance. If a time series meets these conditions, it is considered a white noise process.

When conducting the ADF test, it is necessary to determine the optimal lag length. If the selected lag length is too long, it may lead to inefficient estimation; if it is too short, important information may be omitted, resulting in biased estimates. This study adopts the Akaike Information Criterion (AIC), proposed by Japanese statistician Hiroji Akaike in 1969, to determine the optimal lag length. The lag length corresponding to the minimum AIC value is considered optimal. Referring to Yang (2009), the formula is defined as follows:

$$AIC = T \ln SSE + 2k \quad (8-3)$$

Here, T is the total sample size, SSE is the sum of squared errors (in natural logarithmic form), and k is the total number of parameters to be estimated.

3.4.3.2 Cointegration Test

According to Chen (2013), citing Engle & Granger (1987), cointegration refers to a situation in which a set of non-stationary time series variables has a stationary linear combination; in this case, these variables are said to exhibit a cointegration relationship. There are two main approaches to cointegration testing: the two-step cointegration test proposed by Engle & Granger (1987), and the multivariate cointegration test proposed by Johansen (1988). The two-step method is applicable only when there is a single cointegrating vector among the variables. However, in practice, there may be multiple cointegrating vectors, and the two-step method does not provide an appropriate statistical measure to determine the number of such vectors. Therefore, empirical studies commonly adopt the Johansen cointegration test. The Johansen approach is based on the Vector Autoregression (VAR) model proposed by Sim (1980) and incorporates the corresponding error correction mechanism. If a group of time series variables is cointegrated, there must exist a corresponding error correction model (ECM). Through the ECM, one can fully understand both the short-term dynamic relationships among the variables and the process by which short-term disequilibrium adjusts toward long-term equilibrium. When the Johansen cointegration test indicates the existence of a cointegration relationship among variables, the lagged error correction term representing the long-term relationship should be incorporated into the VAR model, forming a Vector Error Correction Model (VECM). Thus, the variables are influenced not only by their own past values and those of other variables but also by the previous period's disequilibrium.

A VAR model consists of a system of multiple variables and multiple regression equations. In each equation, the dependent variable is expressed as a function of its own lagged values as well as the lagged values of other variables. A general VAR model can be represented as follows:

$$Y_t = A_0 + \sum_{i=1}^z A_i Y_{t-i} + \varepsilon_{yt} \tag{9-1}$$

Here, Y_t is an $(n \times 1)$ vector representing a jointly covariance stationary linear stochastic process. A_0 is an $(n \times 1)$ intercept vector, A_i is an $(n \times n)$ coefficient matrix, and Y_{t-i} is an $(n \times 1)$ vector of lagged values of Y_t . ε_{yt} represents the structural disturbance term, which is an $(n \times 1)$ vector composed of the disturbances associated with the lagged terms of Y_t , and it is assumed to follow a white noise process.

In addition, the error correction model (ECM) established by Engle & Granger (1987) can be expressed as follows:

$$\Delta Y_t = \alpha_1 + \alpha_y e_{t-1} + \sum_{i=1}^z a_i \Delta Y_{t-i} + \sum_{i=1}^z b_i \Delta X_{t-i} + \varepsilon_{yt} \tag{9-2}$$

$$\Delta X_t = \alpha_2 + \alpha_x e_{t-1} + \sum_{i=1}^z c_i \Delta Y_{t-i} + \sum_{i=1}^z d_i \Delta X_{t-i} + \varepsilon_{xt} \tag{9-3}$$

Here, e_{t-1} measures the degree of deviation from long-term equilibrium in period $t - 1$, i.e., the error correction term. α_y and α_x are the error correction coefficients, α_1 and α_2 are intercept terms, and z represents the optimal lag length. ε_{yt} and ε_{xt} are both white noise, while a_i , b_i , c_i , and d_i denote short-term dynamic adjustment coefficients, which indicate whether short-term relationships exist among the variables.

Referring to Su (2023), this study first employs the ADF unit root test to preliminarily examine the data characteristics. If the variables are stationary, a Vector Autoregression (VAR) model is directly used for estimation and analysis. If the variables contain a unit root $I(d)$ (i.e., are non-stationary) and have different orders, belonging to $I(0)$ or $I(1)$ (order less than 2), the Autoregressive Distributed Lag (ARDL) model developed by Pesaran, Shin & Smith (2001) is applied.

If the variables contain a unit root $I(d)$ and include orders up to $I(2)$, the ARDL model is not applicable, as it only supports $I(0)$ and $I(1)$ variables and may lead to biased inference when applied to $I(2)$ data (Nkoro & Uko, 2016). In such cases, following Yang (2015), this study adopts the more flexible Johansen cointegration test to examine cointegration relationships, and then applies the Vector Error Correction Model (VECM) to analyze short-term dynamics. If no cointegration relationship exists, it indicates the absence of a long-term relationship among variables. In this situation, non-stationary variables are differenced and analyzed using a VAR model, with the optimal lag length determined by the Akaike Information Criterion (AIC).

If the variables are all $I(1)$, the Johansen cointegration test is used to determine whether a long-term equilibrium relationship exists. If cointegration is present, a VECM is estimated; if not, the variables are first differenced and analyzed using a VAR model, again with lag length determined by AIC.

Furthermore, even when variables have different integration orders (less than 2), cointegration may still exist after appropriate differencing to achieve a common order. In such cases, the Johansen cointegration test can be applied after transforming the data to the same integration order.

When variables are $I(0)$ and $I(1)$, this study uses the ARDL model to examine whether economic policy uncertainty has a significant impact on social housing rents. According to Li (2022), the ARDL model has three main advantages: (1) it allows for simultaneous analysis of both long-term and short-term relationships; (2) it is suitable for studies with small sample sizes; and (3) it accommodates variables of different integration orders ($I(0)$ and $I(1)$), thereby addressing issues of inconsistent data orders.

According to Su (2023) and Li (2022), the ARDL model developed by Pesaran et al. (2001) allows not only the inclusion of lagged dependent variables but also contemporaneous and lagged independent variables in the regression framework. It does not require all variables to be $I(1)$; as long as they are $I(0)$ or $I(1)$, the model can be applied. Moreover, it resolves issues of differing

integration orders while providing consistent estimates of both long-term equilibrium relationships and short-term dynamics, making it particularly suitable for small-sample studies. Following Su (2023), the ARDL(p, q) model established by Pesaran et al. (2001) is specified as follows:

$$\Delta \ln \text{CPIR}_t = \alpha_0 + \sum_{i=0}^p \beta_i \Delta \ln \text{CPIR}_{t-i} + \sum_{i=0}^q \gamma_i \Delta \ln \text{TEPU}_{t-i} + \delta_i \ln \text{CPIR}_{t-1} + \tau_i \ln \text{TEPU}_{t-1} + \varepsilon_t \quad (10-1)$$

In Equation (10-1), $\Delta \ln \text{CPIR}_{t-i}$ represents the change in the natural logarithm of the Consumer Price Index Rent for period $t - i$, and $\Delta \ln \text{TEPU}_{t-i}$ represents the change in the natural logarithm of the Taiwan EPU index for period $t - i$. ε_t is the error term. $\ln \text{CPIR}_t$ denotes the natural logarithm of the CPI Rent in period t , while $\ln \text{TEPU}_{t-1}$ denotes the natural logarithm of the Taiwan EPU index in period $t - 1$. In Equation (10-1), p represents the lag length of the dependent variable (the natural logarithm of CPI Rent), and q represents the lag length of the independent variable (the natural logarithm of the Taiwan EPU index). α_0 denotes the intercept term.

In the ARDL(p, q) model constructed in this study, p and q represent the lag lengths of the dependent and independent variables, respectively. These lag lengths are selected based on the Akaike Information Criterion (AIC), choosing the optimal lag length that minimizes the AIC value.

According to Su (2023) and Li (2022), after establishing the ARDL model, the Bounds Test proposed by Pesaran et al. (2001) is applied to determine whether a long-term relationship exists between the dependent and independent variables. In this study, the Bounds Test is used to examine whether a long-term cointegration relationship exists between the CPI Rent and the Taiwan EPU index. Following Pesaran et al. (2001), the null hypothesis is specified as follows:

$$H_0 : \delta = \tau = 0 \text{ (no cointegration)} \quad (10-2)$$

Here, δ and τ represent the estimated long-term coefficients of the dependent and independent variables, respectively. If the estimated coefficients fail to reject H_0 , it indicates that there is no long-term cointegration relationship between the variables. Conversely, if the estimated coefficients reject H_0 , it implies that a long-term cointegration relationship exists between the variables.

This study determines the results based on the F-statistic and the critical value bounds provided by Pesaran et al. (2001). In this framework, the lower bound corresponds to $I(0)$, and the upper

bound corresponds to I(1). If the F-statistic is less than I(0), H_0 cannot be rejected, indicating no long-term cointegration relationship. If the F-statistic exceeds I(1), H_0 is rejected, indicating the existence of a long-term cointegration relationship. If the F-statistic falls between I(0) and I(1), the result is inconclusive.

If the test result shows that the F-statistic is greater than I(1), it indicates that a long-term cointegration relationship exists between the CPI Rent and the Taiwan EPU index. In this case, further analysis can be conducted to examine the impact of Taiwan's economic policy uncertainty on the CPI Rent.

3.4.3.3 Granger Causality Test

According to Su (2023), Li (2022), Lin (2013), and Liu (2008), Granger causality was proposed by Granger (1969). It decomposes the relationships among variables into multiple independent regression equations, incorporating both the lagged terms of the dependent variable itself and the lagged terms of explanatory variables. Through this test, one can identify the lead or lag relationships between two variables. The Granger causality model is based on a predictive perspective, examining the "correlation" between the current value of one variable and the past values of other variables.

In order to examine the lead-lag relationship between the real price of social housing rents and economic policy uncertainty, this study establishes the following regression model:

$$\ln \text{CPIR}_t = \alpha_0 + \sum_{i=1}^k \beta_{1i} \ln \text{CPIR}_{t-i} + \sum_{i=1}^k \delta_{1i} \ln \text{TEPU}_{t-i} + \varepsilon_{1i} \quad (11-1)$$

$$\ln \text{TEPU}_t = \alpha_1 + \sum_{i=1}^k \beta_{2i} \ln \text{TEPU}_{t-i} + \sum_{i=1}^k \delta_{2i} \ln \text{CPIR}_{t-i} + \varepsilon_{2i} \quad (11-2)$$

According to Li (2022), when $\delta_{1i} \neq 0$ and $\delta_{2i} = 0$, it indicates that $\ln \text{TEPU}_t$ Granger-causes $\ln \text{CPIR}_t$, representing a unidirectional causal relationship. When $\delta_{1i} = 0$ and $\delta_{2i} \neq 0$, it indicates that $\ln \text{CPIR}_t$ Granger-causes $\ln \text{TEPU}_t$, also representing a unidirectional causal relationship. When $\delta_{1i} \neq 0$ and $\delta_{2i} \neq 0$, it indicates that $\ln \text{TEPU}_t$ Granger-causes $\ln \text{CPIR}_t$, and $\ln \text{CPIR}_t$ also Granger-causes $\ln \text{TEPU}_t$, representing a bidirectional causal relationship. When $\delta_{1i} = 0$ and $\delta_{2i} = 0$, it indicates that there is no causal relationship between $\ln \text{CPIR}_t$ and $\ln \text{TEPU}_t$.

4. Case study

4.1 Basic information

To exemplify above proposed model, this study takes the four social housing cases (three of which have been constructed) currently open for rent in Taichung City as examples. The four cases are not provided by private organizations via the construction method (are not privately-owned social housing projects), of which three are government self-built, and one is a case of donation (divided back) for volume awards. The four cases are all provided by local governments and constructed by the private real estate developer. That is to say, these studied four social housing cases (case A, case B, case C, and case D) are hypothetical privately-owned

social housing projects with real datas. Main indices of these projects are extracted from the information published by the Taichung City Government Housing Development Department (2020) and illustrated in Table 2.

Table 2. Main indices of the studied social housing project

| CASE A Index name | CASE A Index value | CASE A Index name | CASE A Index value |
|---|--------------------|---|--------------------|
| Land area (10 ⁴ m ²) | 0.1441 | Building area of social housing buildings (10 ⁴ m ²) | 0.7726 |
| Social housing suites | 200 | Building area of commercial buildings (10 ⁴ m ²) | 0 |
| Parking spaces for motor vehicles | 50 | floors above ground | 12 |
| Motorcycle Parking | 138 | floors underground | 2 |
| CASE B Index name | CASE B Index value | CASE B Index name | CASE B Index value |
| Land area (10 ⁴ m ²) | 0.9545 | Building area of social housing buildings (10 ⁴ m ²) | 1.9696 |
| Social housing suites | 300 | Building area of commercial buildings (10 ⁴ m ²) | 0.165 |
| Parking spaces for motor vehicles | 154 | floors above ground | 7 |
| Motorcycle Parking | 363 | floors underground | 1 |
| CASE C Index name | CASE C Index value | CASE D Index name | CASE C Index value |
| Land area (10 ⁴ m ²) | 1.2668 | Building area of social housing buildings (10 ⁴ m ²) | 1.159 |
| Social housing suites | 201 | Building area of commercial buildings (10 ⁴ m ²) | 0.0464 |
| Parking spaces for motor vehicles | 112 | floors above ground | 9 |
| Motorcycle Parking | 241 | floors underground | 1 |
| CASE D Index name | CASE D Index value | CASE D Index name | CASE D Index value |
| Land area (10 ⁴ m ²) | 1.9549 | Building area of social housing buildings (10 ⁴ m ²) | 1.7885 |
| Social housing suites | 232 | Building area of commercial buildings (10 ⁴ m ²) | 0.2169 |
| Parking spaces for motor vehicles | 228 | floors above ground | 13 |
| Motorcycle Parking | 372 | floors underground | 3 |

4.2 Model parameters

4.2.1 NPV-relative parameters

According to the proposed valuation model, a lot of parameters should be determined in advance to calculate the NPV of this social housing project, primarily including CIt , COt , and q .

The first parameter about CIt is the average letting rate of social housing buildings and other affiliated businesses (such as commercial buildings). After investigation the supply and demand of the surrounding rental housing market in the four cases, the local demand of social housing buildings and other affiliated businesses (such as commercial buildings) is significantly greater than the supply, the final average letting rate is evaluated at 100%.

The second parameter about CIt is the average monthly rent of social housing buildings. In Taichung City, the current situation is set at 50% of the market price in the first year, set at 60% of the market price in the second year, and set at 70% of the market price in the third year. The low-income or middle-income households that meet the requirements of Article 4 of the "Housing Act" will be set at 65% of the market price from the third year. Finally, their average rent income was set at 60% of the market price based on the concept of average calculation at first. According to market research and comparative analysis, the average monthly rent of similar private rental houses nearby is NT\$205 / m², NT\$170 / m², NT\$155 / m², and NT\$155 / m², respectively. After a 40% discount, the average monthly rent of social housing buildings in Cases A, B, C, and D is NT\$123 / m², NT\$102 / m², NT\$93 / m², and NT\$93 / m², respectively. However, considering the operating period of this case is evaluated in 50 years, in the long run, it is relatively reasonable to evaluate the average monthly rent of social housing buildings based on a 30% discount on the market price. After the 30% discount, the average monthly rent of social housing buildings in Cases A, B, C, and D is NT\$144 / m², NT\$119 / m², NT\$109 / m², and NT\$109 / m², respectively.

The third parameter about CIt is the average monthly rent of other affiliated businesses (such as commercial buildings). According to market research and comparative analysis, the average monthly rent of similar private rental houses nearby is NT\$177 / m², NT\$221 / m², NT\$261 / m², and NT\$205 / m² respectively. This study uses these data directly. In addition, according to the prediction of the future inflation rate of Taichung City, it is assumed that the rent of social housing buildings and other affiliated businesses (such as commercial buildings) will increase by 9% every 3 years (estimated at 3.00% per year).

The fourth and fifth parameters related to CIt are the monthly income of parking spaces for motor vehicles and motorcycle parking. The income is determined by its number, average occupancy rate and monthly rent. According to the market supply and demand situation, the local demand for parking spaces for motor vehicles and motorcycle parking is obviously greater than

the supply. Therefore, the final average occupancy rate is evaluated at 100%. According to market research and comparative analysis, it is estimated that the monthly rents for each parking spaces for motor vehicles in Cases A, B, C, and D are is NT\$2,400 / unit, NT\$2,000 / unit, NT\$1,900 / unit, and NT\$1,700 / unit, respectively. In addition, the estimated monthly rent for each motorcycle parking space in the four cases is NT\$200 / unit, NT\$100 / unit, NT\$150 / unit, and NT\$175 / unit, respectively.

Taking Case B as an example here, the calculation process of the average monthly rent of social housing buildings and the average monthly rent of market price is shown in Table 3.

Table 3. Calculation table of the average monthly rent of social housing buildings and market price

| Case A social housing building | | | | | | |
|--------------------------------|-------------------------------|----------------------|--|--|---|---|
| Room type | Rental area (m ²) | Number of households | The total area of each room type (m ²) | Rent after 40% off (Including management fee) (NT\$ / month) | Rental price after 40% off (NT\$ / month) | Total unit price after 40% discount for each room type (NT\$ / month) |
| One m bedroo | 46.28 | 164 | 7,589.92 | 5,800 | 126 | 951,200 |
| One m bedroo | 49.59 | 27 | 1,338.93 | 6,200 | 126 | 167,400 |
| One m bedroo | 56.20 | 4 | 224.80 | 7,100 | 126 | 28,400 |
| Two m bedroo | 92.56 | 48 | 4,442.88 | 9,800 | 106 | 470,400 |
| Two m bedroo | 95.87 | 9 | 862.83 | 10,200 | 106 | 91,800 |
| Two m bedroo | 102.48 | 26 | 2,664.48 | 10,900 | 106 | 283,400 |
| Two m bedroo | 105.79 | 13 | 1,375.27 | 11,200 | 106 | 145,600 |
| Three bedroo | 125.62 | 4 | 502.48 | 12,800 | 102 | 51,200 |

| | | | | | | |
|---|--------|-----|-----------|---|-----|-----------|
| m | | | | | | |
| Three | | | | | | |
| bedroom | 138.84 | 5 | 694.20 | 14,000 | 101 | 70,000 |
| m | | | | | | |
| Subtotal | | 300 | 19,695.79 | | | 2,189,400 |
| 1 | | | | | | |
| Average rent unit price of all social housing buildings after 40% off (=2,189,400÷19,695.79) (NT\$ /m ² / month) | | | 102 | | | |
| | | | | Average rent unit price of all social housing buildings calculated base on market price (=102÷0.6) (NT\$ /m ² / month) | 170 | |

Note. Considering that the operation period of this case is evaluated in 50 years, in the long run, the average monthly rent of social housing buildings should be more reasonable based on the market price of 30%. After a 30% discount, the average monthly rent of social housing buildings in case A is NT\$119 / m² (= NT\$170 / m² * 0.7).

The first parameter about COt is the purchase cost of land. In the case of social housing built by the private organizations via the construction method, considering the financial feasibility, the land will be rented to construct social housing, and the rent is estimated based on the 4.5% of declared value by reference to the provisions in Table 1. The second parameter about COt is the capital expenditures (construction cost of buildings), includes plan, design and construction supervision cost, direct construction cost, project administration fees and others (including project management cost, price adjustments, the cost of public art, various administrative fees, etc.). After referring to the “Public Construction Project Expenditure Compilation Manual for Construction Projects” formulated by the Public Construction Commission, Executive Yuan, in Taiwan, and the preliminary planning research report on the relevant social housing in Taichung City, the total capital expenditures in Cases A, B, C, and D are NT\$343.17 million, NT\$689.31 million, NT\$261.20 million, and NT\$537.77 million, respectively.

The third parameter about COt is the design and construction supervision cost. According to market research, it can be estimated as NT\$5 million per case. The fourth parameter about COt is loan interest. According to the latest statistics from the Central Bank of the Republic of China (Taiwan), the annual interest rate of borrowed funds is estimated at 3.26%. In addition, the self-owned funds in the investment amount are estimated at 50%, and the borrowed funds are estimated at 50%. These loans will be borrowed from local commercial banks equally in three years of construction stage, and then repaid with maximum capacity in the operation stage.

The fifth parameter about COt is the total loan interest. It is estimated that the total loan interest in case A, case B, case C, and case D is NT\$191.13 million, NT\$383.90 million, NT\$ 162.16 million, and NT\$311.36 million, respectively. The sixth parameter about COt is the operating expenditures, including management and maintenance expenses costs, repair and maintenance costs, fire and earthquake insurance premiums, and depreciation costs. After referring to the

preliminary planning research report of the relevant social housing in Taichung City, it is estimated that the operating expenditures of Case A, Case B, Case C, and Case D during the 50-year operation period is NT\$612.35 million, NT\$1,230.01 million, NT\$519.56 million and NT\$ 997.57 million. The seventh parameter and the eighth parameter related to COt are the depreciation period of social housing buildings and affiliated commercial buildings. After referring to the relevant laws and regulations, both parameters are assumed to be 50 years.

As for q , refer to the preliminary planning research report of relevant social housing in Taichung City, it is evaluated at 4.13%. In addition, referring to Article 22 of the "Housing Act", during the operation of social housing, rental income from spaces used to provide housing, long-term care services, services for the disabled, child-care services, and nursery, shall be exempt from sales tax.

4.2.2 OP-relative parameters

In order to calculate OP part in Equation (5-1) ~ (5-3), six parameters are necessary in total. The first parameter is the maturity time T . According to the aforementioned private real estate developers, after obtaining the land use rights, they can exercise the delayed option of social housing at any time without affecting the construction progress (is an American option). In this case, with reference to the surrounding real estate price changes, the maturity time is estimated as 1 year. That is to say, one year deferral option is considered in valuing this studied social housing project.

The second parameter is the current value S_0 , which is the discounted value at decision making stage and can be estimated on the basis of q (i.e. 4.13%) and income cash flow at operation stage (i.e. 50 years). Take case B as an example, considering parameters in previous section, the annual rent income of social buildings and affiliated commercial buildings in first year is NT\$ 36.26 million, which will increase to NT\$ 36.98 million in second year. With such an increasing trend of rent income, and then deducting operating costs or expenses and profit-seeking enterprise income tax by, S_0 can be calculated as NT\$ 596.73 million.

The third necessary parameter is the investment cost C_0 , which is also a discounted value at decision making stage and can be estimated on the basis of q and the irreversible investment. The cost for land use rights is paid by the private real estate developer for obtaining the option, and thus it should not be included in the irreversible investment (Chen, 2007). The costs that occur in operation stage should not be included, too (Chen, 2007). Because the operation cost would only occur when the commercial buildings are rented out, and it is not irreversible. The investment cost should only include the irreversible investment part. Based on the total project cost of case A and q (i.e. 4.13%), C_0 can be calculated as NT \$ 623.87 million.

The fourth necessary parameter is δ . From the perspective of data availability, only δ induced by cost increase is considered. Take case A as an example, it is obvious that the direct construction cost is the main component of building cost, approximately 91.32% of the construction cost.

In addition, according to the survey, housing construction cost is the main component of the direct construction cost, accounting for about 53% of direct engineering cost. Therefore, the growth rate of total cost can be represented according to the average growth rate of material cost and labor cost, and their proportions are about 60%, 30% respectively. The study selected the local consumer price index (CPI) and per capita salary as their tokens respectively. According to the “National Statistics, R.O.C. (Taiwan)”, the annual increases of CPI and per capita salary from 2020 to 2025 are 1.84% and 2.90% separately. Therefore, the preliminary estimate of the value leakage (δ) for the studied social housing project is about 0.758% ($\approx 60\% * 1.84\% + 30\% * 1.97\%$).

Furthermore, considering that fluctuations in direct construction costs are influenced not only by the aforementioned changes in material and labor costs but also, to a certain extent, by international economic conditions, this study ultimately adopts a conservative approach by applying a 50% weight to the preliminary estimate of δ as the the value leakage (δ) used in this case. After calculation, the adopted δ is 0.99% ($\approx 1.97\% * 50\%$).

The fifth parameter is the risk-free interest rate r_f , which is usually based on the yield of the government’s debt (Chen, 2007). On January 30, 2026, the Central Bank of the Republic of China (Taiwan) announced to sell a thirty-year period national debt with an annual interest of 1.58%, which is adopted as the risk-free interest rate. That is to say, r_f of the studied social housing project is 1.58%.

The sixth parameter is the average volatility of social housing rent. Because social housing is a new type of affordable housing in Taiwan, there is no special statistical data on social housing rent. But, as mentioned before, social housing rent is usually 70% of the rents of similar private rented houses nearby, which are positively correlative to their selling prices. So, the average volatility of commodity houses’ selling price can represent that of social housing rent. From the official real estate information platform in Taiwan, from the third quarter of 2020 to the third quarter of 2025, the average fluctuation of the Taichung City residential price index was 6.57%, as shown in Table 4.

Table 4. Taichung City Residential Price Index and its volatility from the 3rd quarter of 2020 to the 3rd quarter of 2025

| Point in time | Residential price index | Residential price index rate of change to the same quarter last |
|---------------|-------------------------|---|
| Q3 2020 | 109.85 | 5.02% |
| Q3 2021 | 121.01 | 10.16% |
| Q3 2022 | 135.11 | 11.65% |
| Q3 2023 | 143.00 | 5.84% |
| Q3 2024 | 160.66 | 12.35% |
| Q3 2025 | 151.61 | -5.63% |
| Average value | | 6.57% |

In Table 5, a summary of the relative parameters and values of NPV in case B of this study is listed.

Table 5. a summary of the relative parameters and values of NPV in case B

| Variable | Symbol | Description | Value | |
|----------------------------------|----------------------------------|---|---|------------------------|
| NPV-relative parameters | q | Discount rate | 4.16% | |
| | CI _t | Cash inflow of the privately-owned SH project at year t | Shown below | |
| | CO _t | Cash outflow of the privately-owned SH project at year t | Shown below | |
| | | Maximum operation period for SH buildings | 50 years | |
| | | Maximum operation period for possible affiliated commercial buildings | 50 years | |
| | Determination of CI _t | | The average letting rate of SH buildings and affiliated commercial buildings | 100% |
| | | | The average rent of SH buildings | 170 NTD/m ² |
| | | | The average rent of affiliated commercial buildings | 221 NTD/m ² |
| | | | Increase rate of the rent of SH buildings and affiliated commercial buildings | 3% |
| | | | The monthly rent of a parking space | 2,00 NTD |
| Determination of CO _t | | The monthly rent of a motorcycle parking space | 100 NTD | |
| | | Land cost(Rent of soil) in first year | 0.55million NTD | |
| | | The preliminary planning and research | 5 million NTD | |

| Variable | Symbol | Description | Value |
|----------|--------|---|----------------|
| | | expenses | |
| | | Capital expenditure (building cost) | 623.86 million |
| | | The annual loan interest rate | 3.26% |
| | | The total loan interest | 383.90 million |
| | | The depreciation periods of SH buildings | 50 years |
| | | The depreciation periods of affiliated commercial buildings | 50 years |

5. Results and discussions

5.1. Valuation model results

Putting above NPV-relative parameters into Equation (1), the NPV in case A, case B, case C, and case D can be calculated as NT\$-3.92 million, NT\$-27.14 million, NT\$-12.04 million, and NT\$-14.62 million, respectively. Since each NPV is negative, these studied social housing projects seem financially unacceptable, and thus the private real estate developer should not undertake such a privately-owned social housing project. Then, putting above OP relative parameters into Equation (5-2) and (5-3), d_1 and d_2 can be calculated as 0.11 and -0.14 separately in case A, d_1 and d_2 can be calculated as 0.08 and -0.17 separately in case B, d_1 and d_2 can be calculated as 0.08 and -0.17 separately in case C, and d_1 and d_2 can be calculated as 0.09 and -0.15 separately in case D. Further, $N(d_1)$ and $N(d_2)$ can be dug out from the value table of the standard normal distribution function as 0.5438 and 0.4443 respectively in case A, $N(d_1)$ and $N(d_2)$ can be dug out as 0.5319 and 0.4325 respectively in case B, $N(d_1)$ and $N(d_2)$ can be dug out as 0.5319 and 0.4325 respectively in case C, and $N(d_1)$ and $N(d_2)$ can be dug out as 0.5359 and 0.4404 respectively in case D.

Then, putting $N(d_1)$ and $N(d_2)$ in each case, as well as other parameters obtained in section OP-relative parameters into Equation (5-1), the OP values of Case A, Case B, Case C, and Case D can be calculated as NT\$29.29 million, NT\$48.68 million, NT\$20.26 million, and NT\$41.38 million, respectively. Then, adding OP generated by one-year deferral option and passive NPV together, the ENPV of this studied privately-owned social housing projects in Case A, Case B, Case C, and Case D can be calculated to be NT\$25.38 million, NT\$21.54 million, NT\$8.22 million, and NT\$26.76 million. In Table 6, a summary of the relative parameters and values of OP in case B of this study is listed.

Table 6. a summary of the relative parameters and values of OP in case B

| Variable | Symbol | Description | Value |
|------------------------|--------------------|---|--------------------|
| OP-relative parameters | T | The maturity tim | 1 year |
| | S ₀ | The current value | NT\$596.73 million |
| | C ₀ | The investment cost | NT\$623.87 million |
| | δ | The value leakage of the PRH project | 0.99% |
| | r _f | The risk-free interest rate | 1.58% |
| | σ _s | The average volatility of SH rent | 6.57% |
| | d ₁ | $\frac{[\ln(S_0/C_0) + (r_f - \delta + \sigma^2/2)]}{\sigma\sqrt{T}}$ | 0.08 |
| | d ₂ | $\frac{[\ln(S_0/C_0) - (r_f - \delta + \sigma^2/2)]}{\sigma\sqrt{T}}$ | -0.17 |
| | N(d ₁) | The cumulative probabilities of the variable smaller than d ₁ | 0.5319 |
| | N(d ₂) | The cumulative probabilities of the variable smaller than d ₂ | 0.4325 |
| | OP | The option premium, $S_0 e^{-\delta T} N(d_1) - C_0 e^{-r_f T} N(d_2)$ | NT\$48.68 million |
| | ENPV | Real option valuation model at decision making stage of the privately-owned social housing projects | NT\$21.54 million |

Consequently, the studied social housing projects in Case A, Case B, Case C, and Case D become financially acceptable, if taking OP generated by one-year deferral option into consideration. In other words, private real estate developer should build, own and operate (BOO) these four social housing projects, and waiting one year is a better choice than building it immediately.

Regarding these cases of this study, there are five potential influencing factors that will affect ENPV. As for income part, the income from social housing buildings is the biggest contributor, and thus the average rent of social housing buildings is a potential factor. As for the cost part, most cost items (except financial expenses) cannot be changed. Another potential factor is the building area of affiliated commercial buildings, whilst it will affect the cost and income part simultaneously. Among OP-relative parameters, S₀ and C₀ are both affected by above-mentioned NPV relative parameters, while δ, r_f and S are all beyond private real estate developers' control. Among the OP-relative parameters, T is also a potential factor. After private real estate developers obtaining the land use rights, they can exercise the delayed option of social housing at any time without affecting the construction progress. In addition, the rate of return on self-owned funds and interest rate of loan funds are also potential factors.

The influences of these five potential influencing factors on the ENPV of this studied social housing project are calculated and demonstrated in Fig. 2 to Fig. 5. Taking Figure 3 as an example, through sensitivity analysis, it is found that the average rent increase rate of social housing is the most influential indicator affecting the fluctuation of the ENPV. When the average rent drops by less than 2%, the ENPV will become negative. The second largest influencing

indicator is the interest rate of loan funds. Taking case B as an example, when it increases by about 4%, the ENPV will become negative. As regards the maturity time and the building area of affiliated commercial buildings, their influences are too small to be negligible.

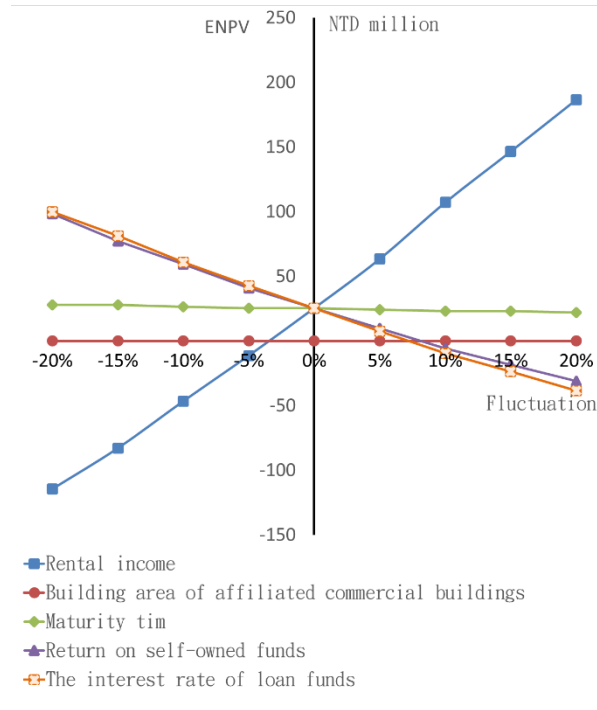


Fig. 2. Results of the sensitivity analysis in case A

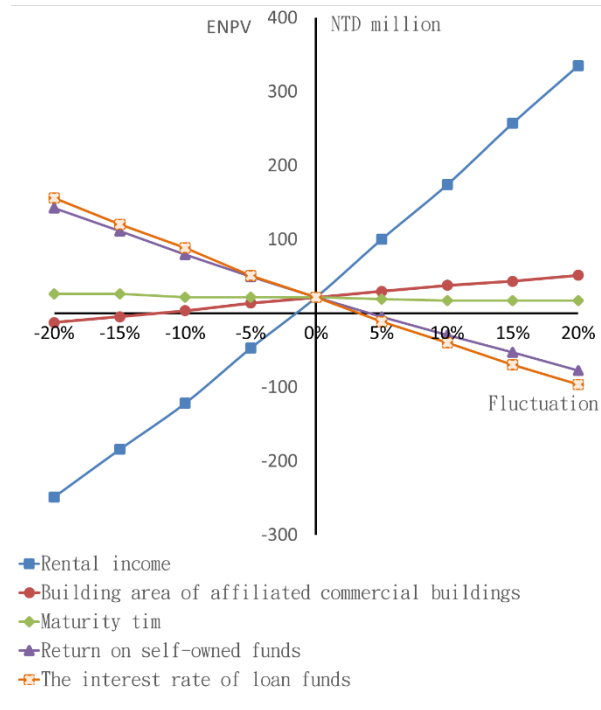


Fig. 3. Results of the sensitivity analysis in case B

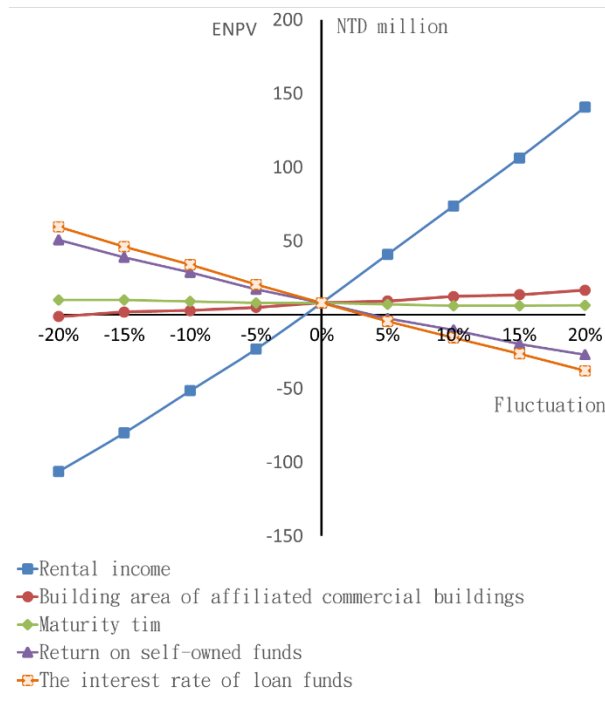


Fig. 4. Results of the sensitivity analysis in case C

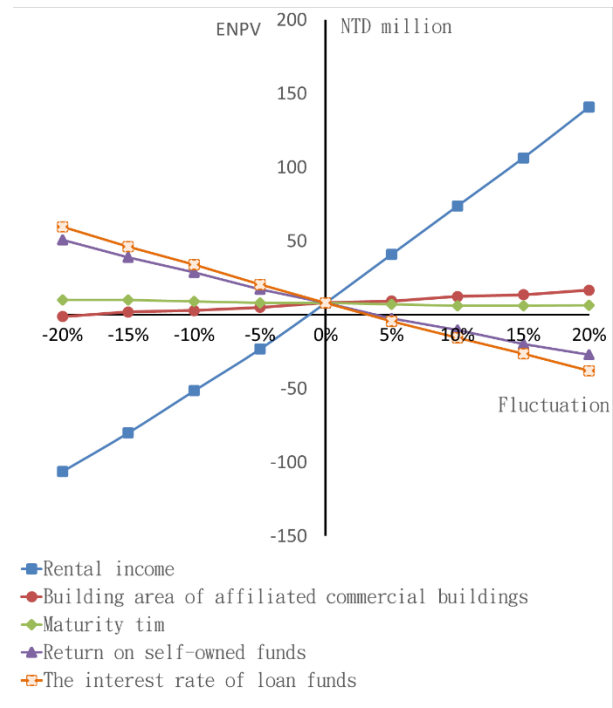


Fig. 5. Results of the sensitivity analysis in case D

5.2. Examining the impact of economic policy uncertainty on rents of privately owned social housing using the Granger causality test

5.2.1. Description of the research sample

The sample period for the Consumer Price Index Rent (CPIR) spans from March 31, 2004, to September 30, 2017. The sample collection dates include March 31, 2004 (March 2004), September 30, 2004 (September 2004), ..., March 31, 2017 (March 2017), and September 30, 2017 (September 2017), with a total of 28 observations and a semiannual frequency.

The sample period for the Taiwan EPU index (TEPU) spans from April 1, 2004, to October 1, 2017. The sample collection dates include April 1, 2004, October 1, 2004, ..., April 1, 2017, and October 1, 2017, with a total of 28 observations and a semiannual frequency.

5.2.2. Descriptive statistics of the research sample data

Table 7 presents the descriptive statistics of the sample data for privately owned social housing in this study, including the descriptive statistics of the Consumer Price Index Rent (CPIR) and the Taiwan Economic Policy Uncertainty (TEPU) index. As shown in Table 7, there are a total of 28 observations during the sample period. The variable CPIR represents the rental index compiled by the Directorate-General of Budget, Accounting and Statistics (Rental Index in the

Consumer Price Index, CPI Rent), while TEPU represents the Taiwan Economic Policy Uncertainty index. This study employs EViews statistical software as the analytical tool.

According to Table 7, both CPIR and TEPU exhibit positive skewness. CPIR shows a platykurtic distribution, while TEPU exhibits a leptokurtic distribution. The Jarque–Bera test results indicate that the p-value for CPIR is greater than 0.1, suggesting that the null hypothesis of normal distribution cannot be rejected. In contrast, the p-value for TEPU is 0, leading to the rejection of the null hypothesis that the series follows a normal distribution.

As noted in Table 7, following Su (2023), , Chen (2013), and Hsu (2011), the J-B value refers to the Jarque–Bera statistic, which is used to test whether a time series follows a normal distribution. The null hypothesis states that the tested variable is normally distributed. Given that a normal distribution has a skewness of 0 and a kurtosis of 3, if the series deviates from these characteristics, the null hypothesis of normality is rejected.

Table 7. Descriptive statistics table of the original data for the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU)

| Variable | Mean | Standard deviation | Minimal value | Median | Maximal value | Skewness | Kurtosis | J-B value | P-value | Sample size |
|----------|----------|--------------------|---------------|----------|---------------|----------|----------|-----------|----------|-------------|
| CPIR | 92.8982 | 1.7481 | 91.07 | 92.14 | 96.78 | 0.8793 | 2.4832 | 3.9199 | 0.140928 | |
| TEPU | 121.8661 | 72.8188 | 52.24 | 122.2454 | 222.45 | 2.8311 | 11.8849 | 129.5024 | 0.000028 | |

Regarding the trend charts of the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU), they are shown in Figures 6 and 7, respectively. The trend of CPIR exhibits a long-term upward pattern, with two mild declining periods. In contrast, the TEPU index shows a long-term pattern of repeated fluctuations, along with a sharp increase. This sharp rise is mainly attributed to major events related to economic uncertainty—such as presidential recall cases and the global financial crisis—which are closely associated with the Taiwan EPU index (with index values exceeding 100). In particular, during the global financial crisis, Taiwan experienced the highest level of economic policy uncertainty.

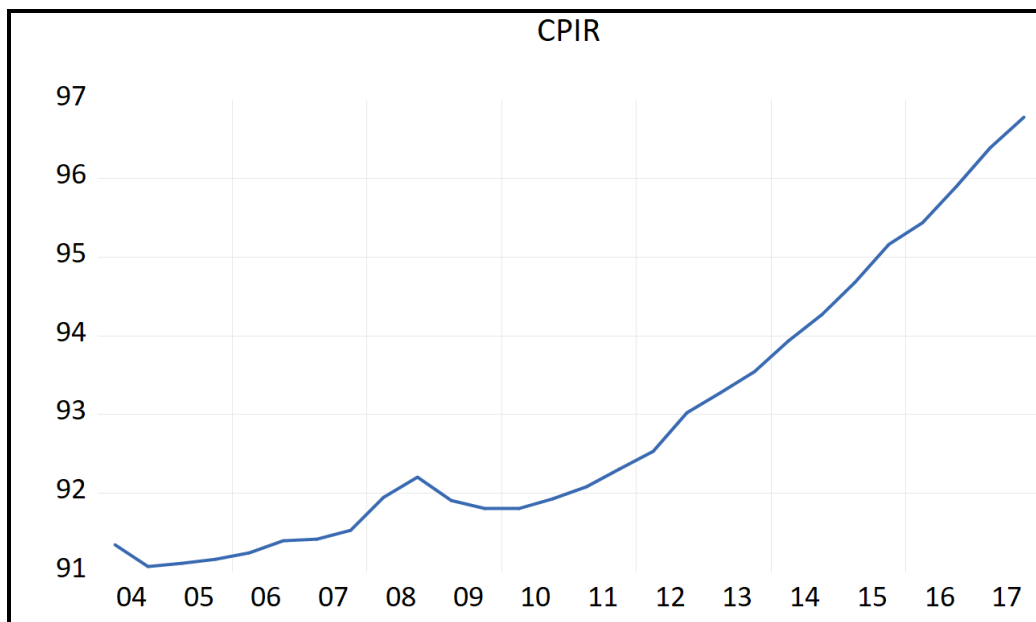


Figure 6. Trend of the Consumer Price Index Rent (CPIR)

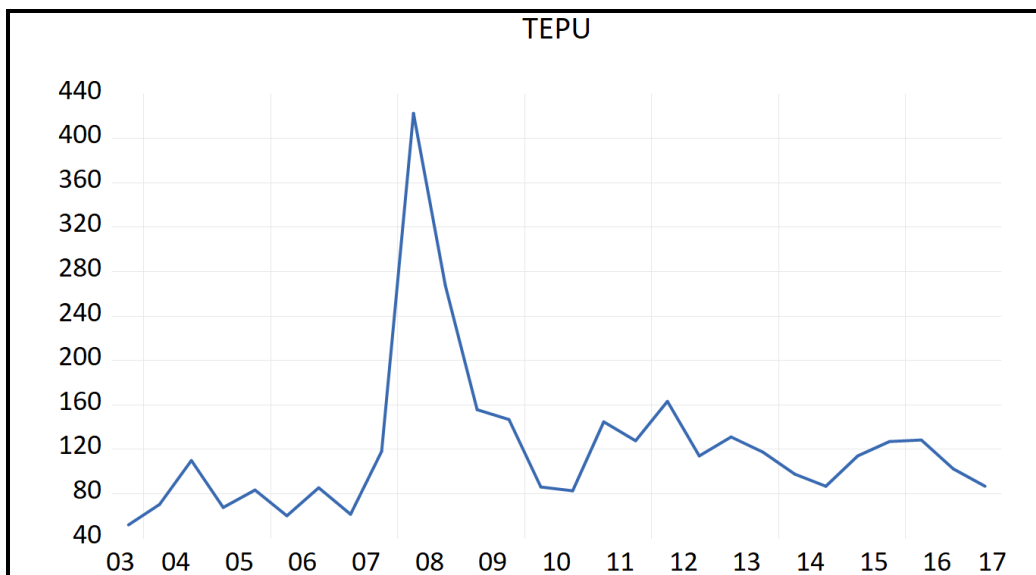


Figure 7. Trend of the Taiwan EPU Index (TEPU)

The distribution charts of the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU) are shown in Figures 8 and 9, respectively. The distribution of CPIR is non-normal, with a left-skewed pattern and portions distributed in both the central and right areas. Similarly, the distribution of TEPU is also non-normal, with the distribution range skewed to the left.

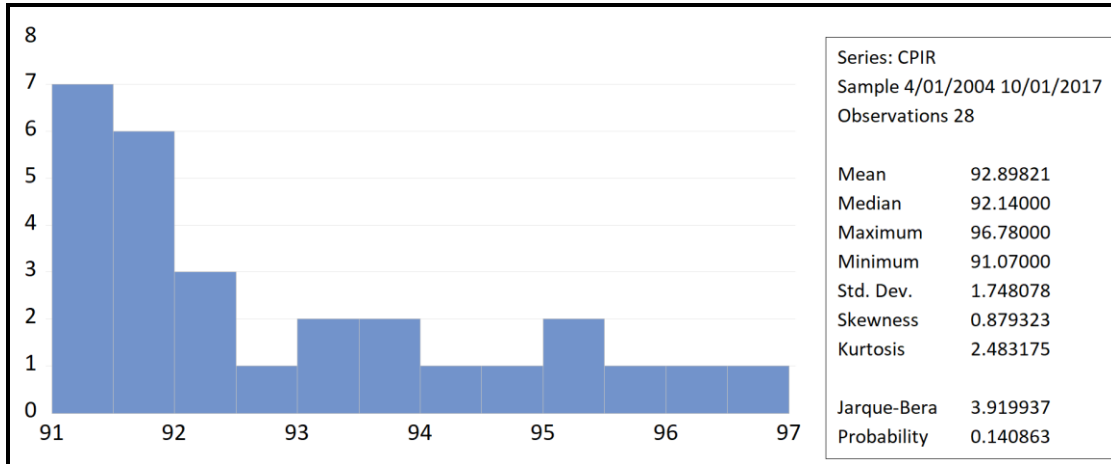


Figure 8. Distribution of the Consumer Price Index Rent (CPIR)

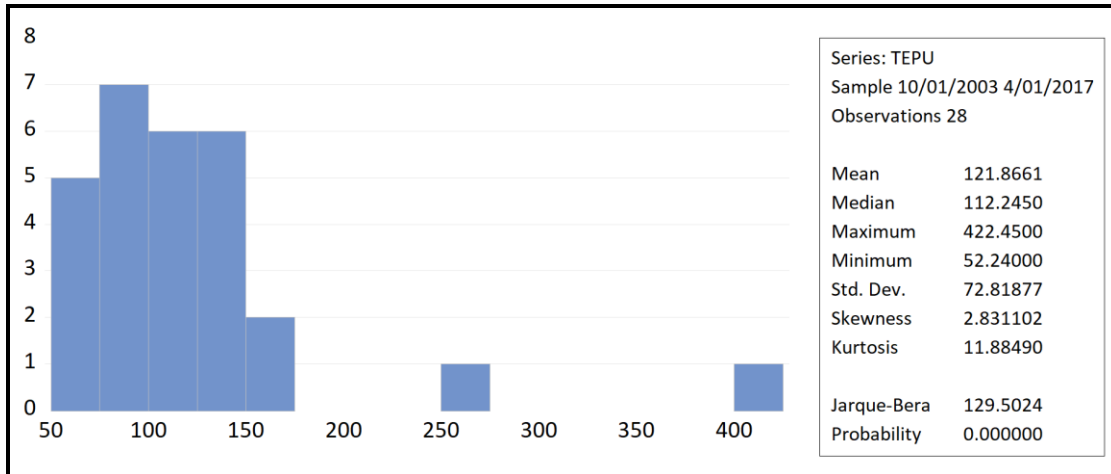


Figure 9. Distribution of the Taiwan EPU Index (TEPU)

5.2.3. Correlation analysis of the research sample

Table 8 presents the correlation analysis between the natural logarithms of the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU). As shown in Table 8, the original data of \ln CPIR and \ln TEPU exhibit a positive relationship, indicating that higher economic policy uncertainty in Taiwan tends to push up rents, leading to an increase in rental prices.

According to previous literature, the relationship between economic policy uncertainty and land prices, housing prices, and rents may be either positive or negative across different countries. Therefore, examining the impact of economic policy uncertainty on land prices, housing prices, and rents helps us understand how these variables respond when economic policy uncertainty arises, and such analysis carries meaningful implications.

Table 8. Summary of the correlation analysis between the natural logarithms of the Consumer Price Index Rent (CPIR) and the Taiwan EPU Index (TEPU)

| Variable | ln CPIR | ln TEPU |
|----------|---------|---------|
| ln CPIR | 1 | 0.1199 |
| ln TEPU | 0.1199 | 1 |

5.2.4. Unit root test of the research sample

Table 9 presents the results of the ADF unit root test for the natural logarithms of the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU).

For the original data of the natural logarithm of CPIR (ln CPIR), under the model with an intercept but without a time trend (Intercept), at the 1% significance level, the p-value is greater than 0.01, and the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value. Therefore, the null hypothesis can be rejected, indicating that the series is stationary and does not contain a unit root. However, under the model with both an intercept and a time trend (Trend and Intercept), at the 1% significance level, the p-value is greater than 0.01, and the absolute value of the t-statistic is smaller than the absolute value of the critical value. Thus, the null hypothesis cannot be rejected, indicating that the series is non-stationary and contains a unit root. In this case, first differencing is required until the series becomes stationary before further analysis can be conducted.

For the original data of the natural logarithm of TEPU (ln TEPU), under both the model with an intercept only (Intercept) and the model with both an intercept and a time trend (Trend and Intercept), at the 1% significance level, all p-values are greater than 0.01, and the absolute values of the t-statistics are smaller than the corresponding critical values. Therefore, the null hypothesis cannot be rejected in all cases, indicating that the series is non-stationary and contains a unit root. As a result, differencing is required until the series becomes stationary before proceeding with further analysis.

Table 9. Summary of ADF unit root test results for ln CPIR and ln TEPU based on original data

| Model | Model with intercept but no time trend (Intersept) | | Model with intercept and time trend (Trend and Intersept) | |
|---------|--|---------|---|---------|
| | t-Statistic | P-Value | t-Statistic | P-Value |
| ln CPIR | 4.1727*** | 1.0000 | -0.5025 | 0.9770 |
| ln TEPU | -3.0307** | 0.0446 | -2.8295 | 0.1996 |

Note. *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. The null hypothesis is rejected when the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value. Under the model with an intercept but no time trend, the

critical values for the ADF test of ln CPIR and ln TEPU (based on original data) at the 1%, 5%, and 10% significance levels are -3.6999 , -2.9763 , and -2.6274 , respectively. Under the model with both an intercept and a time trend, the corresponding critical values are -4.3393 , -3.5875 , and -3.2292 . At the 1% significance level, both ln CPIR and ln TEPU (based on original data) fail to reject the null hypothesis, indicating that all variables are non-stationary.

Since the unit root test using the original data indicates that most series are non-stationary—except for some cases (specifically, the ln CPIR series under the model with an intercept but no time trend)—it is necessary to perform differencing until the series become stationary before proceeding with further analysis.

After taking the natural logarithm of CPIR (ln CPIR) and applying first differencing, under both the model with an intercept but no time trend (Intercept) and the model with both an intercept and a time trend (Trend and Intercept), at the 5% significance level, all series have p-values less than 0.05, and the absolute values of the t-statistics are greater than or equal to the corresponding critical values. Therefore, the null hypothesis can be rejected in all cases, indicating that the data are stationary and do not contain a unit root.

Similarly, after taking the natural logarithm of TEPU (ln TEPU) and applying first differencing, under both model specifications, at the 1% significance level, all series have p-values less than 0.01, and the absolute values of the t-statistics are equal to or greater than the critical values. Thus, the null hypothesis can be rejected in all cases, indicating that the data are stationary and do not contain a unit root. Details are shown in Table 10.

Table 10. Summary of ADF unit root test results for ln CPIR and ln TEPU based on first differencing

| Model | Model with intercept but no time trend | | Model with intercept and time trend | |
|----------|--|---------|-------------------------------------|---------|
| Variable | t-Statistic | P-Value | t-Statistic | P-Value |
| ln CPIR | -3.0265** | 0.0455 | -3.9327** | 0.0250 |
| ln TEPU | -5.3138*** | 0.0002 | -5.2885*** | 0.0012 |

Note. *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. The null hypothesis is rejected when the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value. Under the model with an intercept but no time trend, the critical values for the ADF test of ln CPIR and ln TEPU (based on first differencing) at the 1%, 5%, and 10% significance levels are -3.7115 , -2.9810 , and -2.6299 , respectively. Under the model with both an intercept and a time trend, the corresponding critical values are -4.3561 , -3.5950 , and -3.2335 . For ln CPIR, all first-differenced values reject the null hypothesis, indicating that the variable is stationary. Likewise, for ln TEPU, all first-differenced values reject the null hypothesis, indicating that the variable is also stationary.

5.2.5. Bounds test for cointegration of the research sample

According to the ADF unit root test results in Tables 9 and 10, both the natural logarithm of the Consumer Price Index Rent (ln CPIR) and the natural logarithm of the Taiwan EPU index (ln TEPU) are integrated of order I(1), indicating that they contain unit roots and share the same order of integration. Based on the previously discussed methodology for the Granger causality test, when variables are I(1), this study adopts the more flexible Johansen cointegration test to examine the existence of a cointegration relationship. The analysis is then based on the Vector Error Correction Model (VECM) to observe short-term dynamics. If no cointegration relationship exists, it implies the absence of a long-term relationship between the variables. In such cases, the non-stationary variables are differenced and analyzed using a Vector Autoregression (VAR) model to test relationships among variables, with the optimal lag length determined by the Akaike Information Criterion (AIC).

The results of the Johansen cointegration test are shown in Table 11. For the Consumer Price Index Rent (CPIR), at the 5% significance level, the Trace Statistic is 18.10381, which is greater than the critical value, while the Max-Eigen Statistic is 10.92408, which is less than the critical value. This indicates that the null hypothesis of no cointegration cannot be rejected. In other words, there is no long-term cointegration relationship between CPIR and the Taiwan EPU index (TEPU).

Table 11. Cointegration test between the Consumer Price Index Rent (CPIR) and the Taiwan EPU Index (TEPU)

| Hypothesize No. of CE(s) | Trace Statistic | 0.05 Critical | P- Value | Max- Statistic | 0.05 Critical | P- Value |
|-----------------------------|--------------------|------------------|-------------|-------------------|------------------|-------------|
| None | 18.1038 | 15.4947 | 0.0198 | 10.9241 | 14.2646 | 0.1580 |
| At most 1 | 7.1797 | 3.8415 | 0.0074 | 7.1797 | 3.8415 | 0.0074 |

Table 12 summarizes the cointegration coefficients. From an economic perspective, the signs of the coefficients indicate the direction of the relationship between the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU) (Enders, 2004). Specifically, in the long run, a 1% increase in rents leads to a 6.13% decrease in the Taiwan EPU index (TEPU), while a 1% increase in the Taiwan EPU index results in a 0.16% decrease in the Consumer Price Index Rent (CPIR).

Table 12. Cointegration coefficient table for the Consumer Price Index Rent (CPIR) and the Taiwan EPU Index (TEPU)

| CPIR | TEPU |
|------------------------|------------------------|
| 1.000000 | -0.163107 (0.04590) |
| CPIR | TEPU |
| -6.130959 (9.60961) | 1.000000 |

Based on the above analysis, this study finds that there is no long-term cointegration relationship between the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU). When no cointegration relationship exists between the variables, the non-stationary variables are differenced, and a Vector Autoregression (VAR) model is directly applied for analysis.

5.2.6. Vector Autoregression (VAR) model of the research sample

Following Su (2023), this study adopts the Akaike Information Criterion (AIC) to determine the optimal lag length. As shown in Table 13, the optimal lag length for the Taiwan EPU index (TEPU) is one period.

Table 13. Optimal lag length of the Taiwan EPU Index (TEPU)

| CPIR and TEPU | | |
|---------------|-----------|----------|
| Lag length | LR | AIC |
| 0 | NA | -4.0614 |
| 1 | 105.7022* | -9.2611* |
| 2 | 4.2769 | -9.1490 |
| 3 | 0.6103 | -8.8261 |
| 4 | 2.2966 | -8.6391 |
| 5 | 2.3708 | -8.4910 |
| 6 | 3.6566 | -8.5336 |

5.2.7. Granger Causality Test

The results of the Granger causality test between the Consumer Price Index Rent (CPIR) and the Taiwan EPU index (TEPU) are presented in Table 14. The results show that, at the 10% significance level, the Taiwan EPU index (TEPU) Granger-causes the Consumer Price Index Rent (CPIR), while changes in CPIR do not Granger-cause TEPU. This indicates a unidirectional causal relationship between the two variables.

In other words, changes in the Taiwan EPU index lead to fluctuations in the Consumer Price Index Rent. Combined with the results of the correlation analysis, it can be concluded that Taiwan’s economic policy uncertainty (TEPU) has a significant positive impact on rental prices (CPIR).

Table 14. Summary of the Granger causality test between the Consumer Price Index Rent (CPIR) and the Taiwan EPU Index (TEPU)

| Null Hypothesis | F-statistic | P-Value |
|----------------------------------|-------------|---------|
| TEPU does not Granger Cause CPIR | 4.1832 | 0.0519* |
| CPIR does not Granger Cause TEPU | 0.0285 | 0.8674 |

Note. *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. Based on the p-value, the null hypothesis “TEPU does not Granger-cause CPIR” is rejected. Therefore, at the 10% significance level, TEPU affects CPIR.

6. Conclusions

Social housing in Taiwan is a new form of affordable housing and has been designated as a key focus for reconstructing the affordable housing system, as well as the mainstream direction for future development. Similar to many developed and developing countries, the Taiwanese government has introduced various incentive policies to encourage private sector participation in the provision of social housing.

This study proposes a new social housing provision mode (i.e. privately-owned social housing). Based on related management flexibilities of this mode at decision making stage, only the deferral option is considered in this study. Then, a real option-based valuation model for privately-owned social housing projects is constructed.

Based on the valuation model for privately owned social housing proposed in this study, when considering the option premium (OP) generated by a one-year deferral option, Projects A, B, C, and D are financially viable.

Overall, private enterprises should proceed to develop, own, and operate these four social housing projects. Compared to immediate construction, waiting for one year before proceeding represents a more favorable investment strategy.

According to the sensitivity analysis of the valuation model for privately owned social housing proposed in this study, rental income from social housing buildings is the most influential factor affecting ENPV. The primary factor influencing rental income is σ_s (the average volatility of rents for privately owned social housing). Therefore, when estimating rents for privately owned social housing, accurately predicting the future trend of σ_s is a key determinant of rental levels.

In this study, σ_s is assumed to be 6.57%, which is positive (>0). However, in practice, σ_s is not necessarily always positive, as it is often affected by changes in economic policy. In such cases, further judgment can be made based on the results of the Granger causality test between rental prices and the economic policy uncertainty index. According to the results of this study, at the 10% significance level, the Taiwan EPU index (TEPU) Granger-causes the Consumer Price Index Rent (CPIR), while CPIR does not Granger-cause TEPU, indicating a unidirectional causal relationship. In other words, changes in TEPU lead to fluctuations in CPIR. Combined with the correlation analysis results, Taiwan's economic policy uncertainty (TEPU) has a significant positive impact on rental prices (CPIR).

Taking Taichung City as an example, when calculating the option premium (OP), since TEPU affects CPIR at the 10% significance level, the results of the Granger causality test between CPIR and TEPU can be used to assess the future trend of σ_s .

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