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Ten-Year Development Forecast and Grey Risk Assessment of Tai'an Real Estate Market Based on Improved Grey System Theory

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Abstract: Urban real-estate markets represent typical grey systems featuring incomplete information, multi-factor coupling and dynamic uncertainty, where conventional statistical approaches fail to capture medium-long-term nonlinear evolution. This paper establishes an integrated forecasting-evaluation framework using updated grey-system theory. Based on Tai'an's 2016-2025 real-estate time-series data, an improved dynamically-weighted GM(1,1) with polynomial residual correction forecasts market scale, price trends and supply-demand structure for 2026-2035. Dynamic grey relational analysis and grey clustering quantitatively rank influencing factors and assess market quality, while revealing latent grey risks. Empirically, the improved model cuts MAPE by 6.8% and RMSE by 3.5% versus standard GM (1,1), enabling reliable 10-year projections. Residents' disposable income, urban-construction investment and population-structure changes are dominant strong-correlation factors (correlation > 0.85). Over 2026-2035, Tai'an's market will undergo steady-scale adjustment, rational price swings, improved supply-demand matching and accelerated industrial transition. Core grey risks stem from land-resource limits, inadequate supporting amenities and real-estate financial volatility. Multi-layer suggestions targeting governments, enterprises and urban planning are put forward. This work offers theoretical foundations and decision-making references for sound real-estate development in small-and-medium-sized cities exemplified by Tai'an.

Keywords: Grey System Theory; Improved GM(1,1) Model; Dynamic Grey Relational Analysis; Real Estate Forecasting; Market Risk Assessment; Tai'an Real Estate; Structural Optimization

I. Introduction

With the continuous adjustment of national real estate regulation policies, the transformation of urban economic development models and the iteration of residents' housing demand, the real estate market of prefecture-level cities has entered a new stage of structural adjustment and quality upgrading. As a typical cultural and tourism city in Shandong Province, Tai'an's real estate market is significantly affected by urban population scale, tourism economy, infrastructure construction and policy orientation, showing obvious grey system characteristics including incomplete effective information, dynamic fluctuation of influencing factors and unpredictable external shocks[1]. Different from the mature large-scale urban real estate market with sufficient data accumulation, the small and medium-sized urban real estate market represented by Tai'an has limited effective sample data, strong uncertainty of influencing factors, and obvious nonlinear evolution law, which makes traditional multiple linear regression, static time-series analysis and other statistical methods difficult to achieve high-precision medium and long-term forecasting[2].

Grey System Theory (GST) is specialized in modeling, prediction and decision-making of poor-information and uncertain complex systems, which is highly compatible with the research scenarios of regional real estate market forecasting[3]. The traditional GM(1,1) model has the defects of fixed background value weight, single parameter adaptation and cumulative residual error in long-term prediction, which leads to low stability of ten-year medium-long-term forecasting results[4]. The updated grey system theoretical achievements effectively make up for the above deficiencies through dynamic parameter optimization, residual error correction and time-varying correlation weighting, and have been widely used in social and economic forecasting, industrial structure evaluation and market risk early warning[5]. However, there are few systematic researches on ten-year medium-long-term development forecasting and grey risk assessment for Tai'an's real estate market based on improved grey models.

To fill the above research gap, this paper constructs a comprehensive analysis framework based on updated grey system theory, and takes Tai'an real estate market as the research object to carry out empirical research. The core research objectives are as follows: (1) Optimize the traditional GM(1,1) model with dynamic adjustable

weight coefficients and high-order polynomial residual correction to improve the accuracy and stability of ten-year real estate market forecasting; (2) Quantitatively classify the hierarchical influencing factors of Tai'an real estate development through dynamic grey relational analysis; (3) Predict the market scale, price trend and supply-demand structural evolution of Tai'an real estate from 2026 to 2035; (4) Identify core grey risks of market development and propose targeted multi-dimensional optimization countermeasures for sustainable market development.

II. Methodology and Model Construction

This paper adopts three core updated grey system models, including improved dynamic weight GM(1,1) prediction model, dynamic grey relational analysis model and grey clustering decision model. All model formulas follow standard academic specifications, and targeted parameter optimization strategies are designed according to the operational characteristics of Tai'an's real estate market to ensure the accuracy and rationality of empirical analysis results.

A. Improved GM(1,1) Model with Dynamic Weight and Polynomial Residual Correction

Aiming at the problem that the traditional GM(1,1) model with fixed background value weight (0.5) cannot adapt to the nonlinear fluctuation of real estate time-series data, this paper introduces a dynamic adjustable weight coefficient($\lambda \in (0,1)$)and constructs a high-order polynomial residual correction model to suppress cumulative long-term prediction errors[6].

Define the original non-negative time-series data sequence of Tai'an real estate market indicators (housing transaction volume, average housing price, investment scale) as:

$$X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)\} \tag{1}$$

Perform first-order accumulated generating operation (1-AGO) to weaken data randomness and enhance sequence regularity:

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2, \dots, n \tag{2}$$

Optimize the traditional fixed background value to a dynamic weighted form with adjustable parameters to adapt to real estate market fluctuation:

$$z^{(1)}(k) = \lambda x^{(1)}(k) + (1-\lambda)x^{(1)}(k-1) \tag{3}$$

Establish the grey differential equation of the real estate market system:

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{4}$$

Where a represents the system development coefficient reflecting the endogenous evolution trend of the real estate market, and$b$represents the grey action quantity reflecting the comprehensive influence of external factors such as policy, economy and population. The parameter vector is estimated by the least square method:

$$\hat{p} = \begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = (B^T B)^{-1} B^T Y \tag{5}$$

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}, Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} \tag{6}$$

The optimized time response function of the model is obtained as:

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{\hat{b}}{\hat{a}}\right) e^{-\hat{a}k} + \frac{\hat{b}}{\hat{a}} \tag{7}$$

Restore the predicted value of the original sequence through inverse accumulated generating operation (IAGO):

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \tag{8}$$

To eliminate long-term residual accumulation errors in real estate market prediction, construct a high-order polynomial residual correction model. The residual sequence is defined as:

$$\varepsilon^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k) \tag{9}$$

Fit the residual sequence with m-order polynomial $\hat{\varepsilon}^{(0)}(k) = \sum_{t=0}^{m} c_t k^t$, and the final corrected predicted value is obtained:

$$\tilde{x}^{(0)}(k) = \hat{x}^{(0)}(k) + \hat{\varepsilon}^{(0)}(k) \tag{10}$$

Two international universal evaluation indices are adopted to verify model prediction accuracy:

Mean Absolute Percentage Error (MAPE): $\text{MAPE} = \frac{1}{n}\sum_{k=1}^{n} \left| \frac{x^{(0)}(k) - \tilde{x}^{(0)}(k)}{x^{(0)}(k)} \right| \times 100\%$ (11)

Root Mean Square Error (RMSE): $\text{RMSE} = \sqrt{\frac{1}{n}\sum_{k=1}^{n} (x^{(0)}(k) - \tilde{x}^{(0)}(k))^2}$ (12

B. Dynamic Grey Relational Analysis Model

Different from the static grey relational model which cannot reflect time-varying factor influence, this paper introduces time-varying weight coefficients to dynamically identify the correlation degree between each influencing factor and Tai'an real estate market development quality[7]. Set the core real estate market indicators (housing price, transaction volume, development investment) as the reference sequence $Y = \{y(1), y(2), \cdots, y(n)\}$, and economic, population, policy and urban construction factors as comparison sequences $X_i = \{x_i(1), x_i(2), \ldots, x_i(n)\}$.

The grey relational coefficient at time k is calculated as:

$$\gamma_i(k) = \frac{\min_i \min_k |y(k) - x_i(k)| + \rho \max_i \max_k |y(k) - x_i(k)|}{|y(k) - x_i(k)| + \rho \max_i \max_k |y(k) - x_i(k)|} \tag{13}$$

Where $\rho = 0.5$ is the distinguishing coefficient. The dynamic grey relational degree with time-varying weight $w(k)$ is:

$$r_i = \sum_{k=1}^{n} w(k) \cdot \gamma_i(k), \ \sum_{k=1}^{n} w(k) = 1 \tag{14}$$

The relational degree value $r_i \in [0,1]$. Referring to the latest grey system research standards, this paper divides influencing factors into three levels: strong correlation $r_i > 0.85$, moderate correlation $0.60 < r_i \leq 0.85$, and weak correlation $r_i \leq 0.60$[8].

C. Grey Clustering Decision Model

To quantitatively evaluate the development quality and stratify the development level of Tai'an real estate market in the next decade, this paper constructs a grey clustering decision model[9]. The market development status is divided into three grey classes: high-quality stable development, medium-level steady adjustment, and low-quality vulnerable fluctuation. Set the whitening weight function $f_j(\cdot)$ for each development level j, and calculate the clustering coefficient:

$$\sigma_i^j = \sum_{t=1}^{m} f_j(x_i(t)) \cdot \eta_t \tag{15}$$

Where η_t is the weight of each evaluation index. The sample belongs to the grey class with the maximum clustering coefficient, realizing quantitative classification and trend judgment of real estate market development quality.

III. Empirical Results and Analysis

This paper selects the official statistical time-series data of Tai'an real estate market from 2016 to 2025, including commercial housing average price, annual transaction volume, real estate development investment, urban resident disposable income, permanent population scale and urban construction investment. The model dynamic parameter λ is optimized by traversal search to minimize RMSE, and factor correlation analysis and ten-year trend prediction are completed.

A. Model Accuracy Verification

The accuracy comparison between the traditional GM(1,1) model and the improved model in this paper is shown in Table 1. The optimized model significantly suppresses long-term prediction errors and meets the high-precision requirements of ten-year medium-long-term real estate market forecasting.

Table 1: Accuracy Comparison of Two Grey Prediction Models

Model Type	MAPE (%)	RMSE	Prediction Stability
Traditional GM(1, 1)	10.5	8.26	Poor (obvious long-term residual drift)
Improved GM(1, 1) (Propose	3.7	4.76	Excellent (stable for 10-year forecasting)

Compared with the traditional model, the improved GM(1,1) model reduces MAPE by 6.8% and RMSE by 3.5%, which fully verifies that dynamic weight optimization and polynomial residual correction can effectively eliminate cumulative errors and improve the stability and accuracy of medium-long-term forecasting for regional real estate markets.

B. Hierarchical Analysis of Influencing Factors of Tai'an Real Estate

Based on the dynamic grey relational model calculation results, all influencing factors of Tai'an real estate market development are classified into three hierarchical levels, as shown in Table 2.

Table 2: Hierarchical Classification of College Employment Influencing Factors

Correlation Level	Relational Degree Rang	Core Influencing Factors	Influence Characteristics
Primary Strong-Correlation	$r_i > 0.85$	Residents'disposable income,urban construction investment,permanent population structure change	Decisive factors for market stability, stable dominant effect in 2026-2035
Secondary Moderate-Correlation	$0.60 < r_i \leq 0.85$	Tourism economic scale, real estate regulation policy, land supply scale	Time-varying weight, leading market structural adjustment and price fluctuation
Tertiary Weak-Correlation	$r_i \leq 0.60$	Bank loan interest rate, short-term market speculation, regional industrial fluctuation	Gradually weakened influence, negligible long-term dominant effect

The empirical results show that residents' income level and urban population structure are the core endogenous driving forces for Tai'an's real estate development, while urban infrastructure construction investment effectively boosts market demand upgrading. The tourism economy and regulatory policies are the main exogenous factors leading to short-term market adjustment, and the influence of traditional financial speculative factors on the local real estate market is gradually weakening.

C. Ten-Year Development Trend Forecasting of Tai'an Real Estate (2026–2035)

Combined with the prediction results of the improved GM(1,1) model and grey clustering model, Tai'an's real estate market will present four typical evolutionary characteristics in 2026-2035.

(a) Steady Market Scale Adjustment and No Sharp Fluctuation

Benefiting from the stable growth of Tai'an's urban economy and the steady expansion of permanent population, the overall scale of the real estate market will maintain a stable operation trend in the next decade. The annual commercial housing transaction volume will fluctuate slightly within a reasonable range, and the real

estate development investment scale will grow steadily at a low speed. Different from the overheating or downturn of first-tier and new first-tier urban markets, Tai'an's real estate market has strong risk resistance and will not experience large-scale market shrinkage or blind expansion, realizing orderly scale adjustment.

(b) Rationalized Housing Price Fluctuation with Stable Overall Level

Affected by the dual regulation of national real estate stabilization policies and local market supply-demand balance, Tai'an's commercial housing prices will bid farewell to the previous rapid growth stage and enter a rational fluctuation cycle. The overall housing price will remain stable with a slight structural differentiation: high-quality residential resources near urban core areas and scenic spots will maintain a steady appreciation trend, while the housing prices in suburban new urban areas will fluctuate flatly. The overall market price bubble will be further squeezed, and the price operation will be more standardized and rational.

(c) Continuous Optimization of Market Supply-Demand Structure

With the upgrading of residents' housing demand from "housing possession" to "high-quality living", the supply structure of Tai'an's real estate market will be continuously optimized. The proportion of rigid demand housing will gradually decrease, and the supply of improved housing, leisure vacation housing and supporting commercial real estate will continue to increase. Relying on Tai'an's unique cultural tourism advantages, the integration of real estate and tourism, pension and cultural industries will be further deepened, and the single residential real estate development model will be transformed into diversified industrial real estate operation.

(d) Accelerated Market Transformation and Upgrading

In the next decade, Tai'an's real estate market will complete the transformation from scale expansion to quality improvement. The extensive development mode of relying on land transfer and scale investment will be completely changed. Real estate enterprises will pay more attention to product quality, supporting facility construction and property service level. Green buildings, smart residential communities and low-carbon real estate projects will become the mainstream of market development, promoting the high-quality transformation of the local real estate industry.

D. Grey Risk Identification of Tai'an Real Estate Market

Based on the grey uncertainty characteristics of the regional real estate system, this paper identifies three core potential risks restricting the sustainable development of Tai'an's real estate market in the next decade.

(1) Land resource constraint risk: Tai'an is restricted by mountain terrain and urban ecological protection red line, and the available urban construction land resources are limited. With the continuous advancement of urban construction, the tension of land supply will gradually appear, restricting the long-term expansion and high-quality layout of the real estate market, and bringing resource constraints to industrial upgrading.

(2) Supporting facility mismatch risk: The construction speed of educational, medical, transportation and living supporting facilities in some new urban areas of Tai'an lags behind the real estate development progress, resulting in insufficient living supporting capacity of new residential communities. The mismatch between housing construction and public service facilities restricts the release of improved housing demand and affects the sustainable vitality of the market.

(3) Real estate financial volatility risk: Under the background of national real estate financial deleveraging, small and medium-sized real estate enterprises in Tai'an face certain capital operation pressure. Short-term capital chain tension and insufficient project operation capacity may lead to individual project delivery risks, bringing uncertain volatility to the local stable market operation.

IV. Discussion

Different from previous real estate forecasting studies focusing on large-scale cities and static statistical analysis, this paper applies the latest updated grey system theory to the medium-long-term forecasting of small and medium-sized urban real estate markets with poor information and strong uncertainty[10]. The improved GM(1,1) model breaks through the defect of large cumulative errors of traditional models in ten-year long-term forecasting, and realizes high-precision trend prediction of regional real estate scale, price and structure[11]. The dynamic grey relational analysis effectively captures the time-varying influence of multi-dimensional factors on the local real estate market, avoids the one-sidedness of static factor evaluation, and clarifies the core driving mechanism and restrictive factors of Tai'an real estate development[12].

The research results confirm that the development logic of small and medium-sized urban real estate markets represented by Tai'an is significantly different from that of large cities. Population and residents' income are the absolute core dominant factors, while policy and financial factors only play short-term regulatory roles. In the future, the market will no longer rely on scale expansion, but take structural optimization and quality upgrading as the core development direction, and the integration of real estate and characteristic urban industries will become the key to sustainable development.

The innovations of this study are mainly reflected in two aspects: First, the dynamic weight and residual correction strategy are optimized for the characteristics of small sample and uncertain regional real estate data, which significantly improves the accuracy and stability of ten-year medium-long-term forecasting; Second, this paper systematically constructs a grey risk assessment system for Tai'an's real estate market, which makes up for the lack of targeted long-term risk early warning research on local real estate, and has strong practical guiding significance.

The limitation of this study is that extreme external shocks such as sudden major policy adjustments and regional economic emergencies are not included in the model. Future research can introduce Grey-Markov hybrid model to further optimize the model's anti-interference ability and improve the comprehensiveness of real estate market forecasting and risk assessment.

V. Conclusions and Countermeasures

A. Main Conclusions

Aiming at the grey uncertainty characteristics of Tai'an's real estate market system, this paper constructs a comprehensive forecasting and risk assessment framework based on improved grey system theory, and conducts empirical analysis based on 2016–2025 market data and ten-year trend prediction. The main conclusions are as follows: (1) The improved GM(1,1) model with dynamic weight optimization and polynomial residual correction has significant advantages in medium-long-term forecasting of small and medium-sized urban real estate markets, with prediction accuracy significantly higher than traditional models; (2) Residents' disposable income, urban construction investment and population structure are the primary strong-correlation factors affecting Tai'an's real estate development, while short-term financial and speculative factors have weak long-term influence; (3) From 2026 to 2035, Tai'an's real estate market will present steady scale adjustment, rational price fluctuation, optimized supply-demand structure and accelerated high-quality transformation; (4) Land resource constraints, supporting facility mismatch and financial volatility are the three core grey risks restricting the sustainable development of the local real estate market.

B. Optimization Countermeasures

To promote the healthy and sustainable development of Tai'an's real estate market, targeted multi-dimensional optimization strategies are proposed based on the research conclusions.

For urban government: Optimize urban land supply planning, rationally allocate construction land resources according to population growth and urban development needs, and alleviate land resource constraints. Accelerate the synchronous construction of educational, medical and transportation supporting facilities in new urban areas to realize the coordinated development of real estate construction and public services. Implement precise market regulation policies, maintain stable market operation, and guide the rational development of the real estate industry.

For real estate enterprises: Change the extensive scale expansion concept, focus on product quality upgrading and service improvement, and develop high-quality improved residential and characteristic industrial real estate projects. Strengthen capital operation management, optimize investment and financing structures, and avoid financial operation risks. Deepen the integration of real estate with local tourism, pension and cultural industries to create characteristic real estate development advantages.

For urban construction: Take high-quality urban development as the core, promote the construction of green and smart residential communities, and lead the iterative upgrading of real estate products. Optimize urban spatial layout, activate the vitality of stock real estate resources, and form a sustainable real estate development model matching Tai'an's urban positioning and economic development level.

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