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A synergistic study of urban green development path and economic growth based on polynomial regression algorithm

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Abstract Green development is an important support for realizing high-quality urban economic growth. The study utilizes polynomial regression algorithms and response surface analysis to investigate the impact of urban green development paths on economic growth, and conducts regression analysis and robustness tests on sample data from multiple cities. It is found that the slopes of the consistency curve and the inconsistency curve are both significantly positive at the 5% level, the curvature of the former is positive, and the curvature of the latter is negative, both of which are not significant, and the results of the robustness analysis are consistent. The results indicate that urban green development paths consistent with green actions do not necessarily promote economic growth, and cities with high levels of both green development paths and green actions have better economic growth compared to cities with low levels of both green development paths and green actions. At the same time, a high green development path-low green action combination promotes more synergistic economic growth than a low green development path-high green action combination. This paper studies the relationship between urban green development paths and synergistic economic growth from a consistency perspective, which is of great significance in guiding the government on how to better guide green strategies and economic development.

Index Terms polynomial regression algorithm, response surface analysis, urban green development path, economic growth

I. Introduction

In recent years, people's attention to green development has gradually risen, and more and more countries and regions have begun to pay attention to how to realize sustainable development while urban economic development, especially in addressing climate change and environmental protection [1]-[4]. However, most people believe that green development and economic growth are contradictory to each other, and think that the pursuit of green development will inevitably inhibit economic growth [5], [6]. In fact, the development of green economy is not to inhibit economic development, but to realize the upgrading of economic growth, and the two are synergistic [7-8].

With many countries through the active development of green economy, it has promoted the rise of new industries such as new energy, energy conservation and environmental protection, clean energy, etc. These new industries not only bring new growth momentum for the economy, but also improve the industrial technology level and competitiveness, and promote the improvement of economic efficiency [9]-[12]. Economic growth is the source power of continuous progress and development of human society [13]. However, the unreasonable economic development mode of cities has caused environmental problems such as air, water, soil, etc., which bring threats to people's living environment, and the promotion of sustainable development and green economy is no longer just an environmental protection issue, but has become one of the common constraints and pursuits of human beings [14]-[17]. In order to promote the coordination of sustainable urban development and economic growth, the joint efforts of the government, enterprises and all aspects of society are needed to achieve economic development, environmental protection and people's happiness by strengthening publicity and popularizing education, guiding citizens to enhance their awareness of environmental protection, and forming an environmentally friendly civilization and consumerism in the whole society [18]-[21].

Literature [22] examined the spatial differentiation pattern and correlation characteristics of urban green space ratio, urban green space coverage and public green space area per capita, and utilized the least squares method to quantify the impact of economy on urban greening, revealing the existence of significant spatial dependence of urban greening value, which helps to further coordinate the development of urban greening and economic growth. Literature [23] analyzed the impact of China's National Forest City (NFC) policy on economic growth, and found through data analysis that NFC promotes economic growth, and it improves environmental conditions by providing ecosystem services that increase green vegetation, purify air quality, and mitigate the heat island effect. Literature [24] took Jiangsu Province as an example, proposed a comprehensive index of eco-efficiency, evaluated the eco-efficiency of several cities by using the entropy-weighted TOPSIS method, explored the relationship between economic growth and eco-efficiency, revealed the large differences in eco-efficiency in Jiangsu, and put forward the suggestions of adjusting the industrial structure and improving eco-efficiency. Literature [25] proposed a two-step geometric mean method and constructed a comprehensive framework for the relationship between green transition propulsion on sustainability and coordination at the national and provincial levels, indicating that green transition has a facilitating effect on regional economic growth at the national level, and facilitates the coordinated development of regional economy at the provincial level. Literature [26] analyzes the external correlation and internal relationship between the environment and the economy based on representative economic and environmental indicators, emphasizing that environmental protection slows down economic growth in the short term, while long-term environmental protection improves the infrastructure for economic development, and that the two will be more closely coordinated in promoting the development of a green economy. Literature [27] constructed an indicator evaluation system for economic, ecological environment and health systems based on the perspective of green production, and analyzed the coupled and coordinated relationship among economic, ecological environment and health systems in China's green production, stating that paying attention to the coordinated relationship among green production systems is an important way to achieve the goal of green, healthy and sustainable development. By evaluating the coordinated development of provinces, literature [28] reveals that the coordinated development of most regions continues to improve, but still remains in a transitional state of coordinated development, which is due to the unstable effectiveness of the current pollution control in China, and proposes strategies to cope with it. Literature [29] discussed the coordination of marine ecological protection and economic development in depth, by constructing a coordinated development model of the two, and the results pointed out that the marine ecological protection and economic development showed a trend of sustainable development, and that the coordinated development of the two was impeded, and put forward suggestions such as strengthening ecological environment governance. Literature [30] emphasized the importance of the synergistic development of economic growth and environmental protection, and by including urban climate change into the framework of cross-system coupling analysis, and using the coupled degree of coordination (CCD) model to assess its coordination with economic growth, it revealed that the CCD has obvious spatio-temporal heterogeneity. Literature [31] investigated the temporal and spatial changes in the coupled coordination relationship between urbanization and green development (GD) in coastal cities, specified that the coupled coordination relationship is improving, but the current ecological environmental protection is insufficient to support the coordinated development of these two, and put forward suggestions to promote the coordinated development of urbanization and green development. Literature [32] takes county-level administrative districts as research units, and divides Sichuan Province into economically backward zones, ecological crisis zones and so on based on the median values of the ecological quality index and the economic growth index of each unit, and carries out research on the coupling and coordination degree of each unit, which reveals the significant differences in the distribution characteristics of the various sub-regions and puts forward the sustainable development suggestions in a targeted manner, which provides guidance for the formulation of regional sustainable development strategies. Literature [33] proposes an evaluation index system for manufacturing enterprises in the context of carbon peak and carbon neutral targets, and evaluates the coupled development level of this manufacturing enterprise by establishing an evaluation model and comprehensive evaluation indexes, indicating that the coupled development of economic growth and ecological environment of the enterprise is in a stable and rising state.

The study focuses on urban green development paths and green actions, and from the perspective of consistency, puts forward the research hypotheses related to the impact of three scenarios on economic growth: whether they are consistent or not, the degree of consistency and the direction of incoherence, and analyzes them based on polynomial regression and response surface analysis techniques using the panel data of 20 cities as the object of the study. The research hypotheses are tested through descriptive analysis, correlation analysis and benchmark analysis regression of each variable, and the robustness test is carried out by using both lagged dependent variables and supplementary omitted variables to confirm the robustness and validity of the regression results. Finally, based on the four dimensions of population agglomeration, industrial structure, technological innovation and opening up to the outside world, countermeasure suggestions for synergizing urban green development and economic growth are explored.

II. Theoretical analysis and hypotheses

II. A. Theoretical foundations

Both urban green development paths and green actions affect stakeholders' perception of the city's greenness, which in turn affects the city's economic growth. This study suggests that urban green development paths mainly affect stakeholders' perceptions of enthusiasm for the city's green strategic intentions, while urban green actions mainly affect stakeholders' perceptions of the city's ability to solve environmental problems. Consistent (inconsistent) combinations of urban green development paths and actions affect the consistency of stakeholders' perceptions of the city's green enthusiasm and green capability, which in turn affects economic performance.

Urban green strategies are categorized into four types from the dimensions of urban green development paths and actions and green actions, and Figure 1 shows the types of urban green development paths and green actions combinations. Among them, types ① and ② are consistent cases, consistent urban green development paths and action combinations will not cause cognitive bias of stakeholders, and cities will not waste resources due to some unnecessary friction. Types ③ and ④ are inconsistent cases, where inconsistent urban green development paths and action combinations are likely to cause cognitive bias among stakeholders, and cities will waste resources due to unnecessary friction.

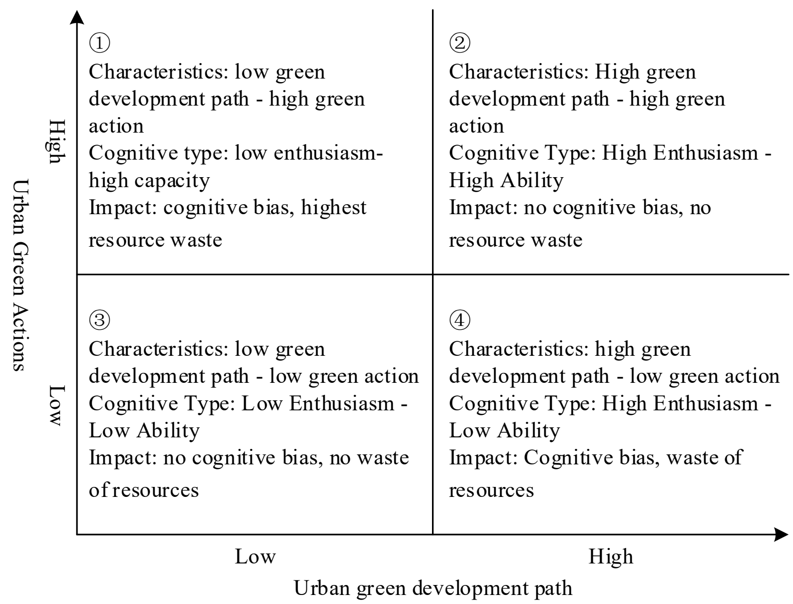

Figure 1: The combination of green development paths and green actions in cities

II. B. Research hypotheses

Based on the influence of the consistency or inconsistency, degree of consistency and direction of inconsistency of cities' green development paths and green actions on the synergy of cities' economic growth, the following research hypotheses are proposed:

H1: Cities with consistent green development paths and green actions will obtain higher economic growth benefits compared to those cities with inconsistent green development paths and green actions. That is, compared with those cities with inconsistent green development paths and green actions, cities with consistent green development paths and green actions will have higher economic growth benefits.

H2: Cities with high congruence between green development paths and green actions will achieve higher economic performance compared to those with low congruence between green development paths and green actions. That is, cities with better development paths and actions in green areas will have higher economic growth benefits compared to cities with poor development paths and actions in green areas.

H3: Cities with high green development paths and low green actions will achieve higher economic performance compared to cities with low green development paths and high green actions. That is, cities with better development paths and poorer actions will have higher economic performance than cities with poorer development paths and better actions in green areas.

III. Study design

III. A. Sample and data

The panel data of 20 cities in a region are selected as the research object. Considering that there is a lag effect in the impact of urban green strategy on economic growth benefits, this study selects the data of explanatory variables and control variables in 2016-2023, while for the data of explanatory variables, the data are selected in 2017-2024. Among them, the data on urban green actions come from the China Research Data Service Platform, the data on environmental regulation come from the China Economic and Social Big Data Research Platform, and the other data on urban green development paths and economic growth benefits come from the Cathay Pacific database.

III. B. Variable settings

III. B. 1) Explained variables

Economic Growth Effectiveness (EG). This study chooses the GDP level to measure the city's economic growth benefits. Considering that there is a lagged effect in the impact of green strategies on urban economic growth benefits, the return period of green investment is long. In this study, the urban economic growth benefits are treated with one lag period.

III. B. 2) Explanatory variables

Urban Green Development Path (UGDP). Urban Green Development Path measurement indicators include environmental protection concept, environmental protection goal, environmental protection management system system, environmental protection education and training, environmental protection special action, environmental incident emergency response mechanism, and environmental protection honor or award.

Urban Green Action (UGA). Urban green actions are in various forms and data acquisition is difficult, and there are large differences in the measurement of green actions in existing studies. In this paper, four primary indicators and 19 secondary indicators are selected to measure urban green actions:

(1) Environmental regulation and certification: pollution monitoring enterprises, pollutant discharge compliance, environmental accidents, environmental violations, and ISO environmental system certification.

(2) Pollution Emissions: Wastewater Emissions, COD Emissions, SO_2 Emissions, CO_2 Emissions, Soot and Dust Emissions, Industrial Solid Waste Generation.

(3) Environmental governance: environmental protection investment, waste gas emission reduction and governance, waste water emission reduction and governance, dust and soot governance, solid waste utilization and disposal, noise and light pollution and other governance, clean production implementation.

(4) Disclosure carriers: disclosure in annual reports, social responsibility reports, environmental reports, etc.

III. B. 3) Control variables

The relationship between urban green development path and economic growth synergy is not the result of a single factor, but is influenced by a number of factors, including the population concentration level, i.e., population density (P), the level of industrial structure (IS), the level of technological innovation (TI), and the degree of openness to the outside world (FDI), and therefore, these four variables are selected as control variables.

III. C. Measurement models

Based on polynomial regression and response surface analysis techniques, the influence of explanatory variables and their "matching relationships" on the explanatory variables can be more accurately and clearly displayed through three-dimensional graphs, polynomial regression can deal with the nonlinear relationship between variables, while response surface analysis can provide more intuitive graphical results, so that the matching relationship between variables and the influence effect can be clear at a glance.

Polynomial regression is an important form of regression analysis in which the relationship between the independent variable x and the dependent variable y is modeled as a polynomial regression model of order greater than one. In regression analysis, polynomial regression models are often considered a special case of multiple linear regression. Starting with multivariate linear regression, the definition as well as the characteristics of polynomial regression are presented.

III. C. 1) Multiple linear regression algorithms

In multiple linear regression, the dependent variable y is described as a weighted sum of the independent variables $x=\left(x_1,x_2,\cdots,x_j\right)$:

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\cdots+\beta_jx_j \tag{1}$$

where the weights $\beta=\left(\beta_0,\beta_1,\beta_2,\cdots,\beta_j\right)$ are the model parameters to be estimated. For each independent variable $x=\left(x_1,x_2,\cdots,x_j\right)$ in a certain dataset D, one obtains:

$$\hat{y}=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\cdots+\beta_jx_j \tag{2}$$

Let $x'=(1,x_1,x_2,\cdots,x_j)^T$, then the equation can be written as:

$$\hat{y}=\beta\cdot x' \tag{3}$$

where the predicted value $\hat{y}$ is the model's estimate of y. The difference between the predicted value and the actual value is calculated using a loss function, which can quantify the predictive performance of the model parameter β on this dataset.

The following are the main types of loss functions commonly used in regression prediction:

The mean square error, also called the L2 error, is given by:

$$MSE=\frac{1}{n}\sum_{i=1}^{n}\left(y_i-\hat{y}_i\right)^2 \tag{4}$$

This method is the most common loss function in regression prediction, and it measures the predictive power of the model by calculating the sum of the squares of the distances between the predicted and actual values.

The mean absolute error, also known as the L1 error, is given by:

$$MAE=\frac{1}{n}\sum_{i=1}^{n}\left|y_i-\hat{y}_i\right| \tag{5}$$

Compared to the mean square error, this loss function is more tolerant of noisy points and does not assign extremely high errors to a few outliers. However, during model optimization, this loss function assigns larger errors to smaller distances (distances less than 1), affecting model convergence.

The Huber loss combines the advantages of the above two loss functions; it is comparable to the mean absolute error when the error is large and becomes the mean square error when the error becomes small. In this way, it can reduce the impact of outlier samples and accelerate the convergence of the model. Its formula is:

$$L_\delta\left(y,\hat{y}\right)=\begin{cases}\frac{1}{2}\left(y-\hat{y}\right)^2 & for\left|y-\hat{y}\right|\le\delta\\ \delta\left|y-\hat{y}\right|-\frac{1}{2}\delta^2 & otherwise\end{cases} \tag{6}$$

In addition to this, there are more robust loss functions such as quantile loss and Log-Cosh loss. In linear regression, the most commonly used loss function is the mean square error, and since the mean square error is sensitive to outlier samples, the more robust Huber regression with quantile regression has emerged on top of linear regression.

III. C. 2) Polynomial Regression Algorithm

In many cases, the dependent variable y is nonlinearly related to the independent variable x, which makes it difficult for a linear regression model to generate a model with a good fit. By introducing higher order terms for the independent variables, the nonlinear relationship of the data can be fitted to achieve higher fitting accuracy. Polynomial regression analysis is a statistical analysis method that models the dependence of the independent variable on the dependent variable usually used when the independent variable and the dependent variable have a nonlinear relationship.

When modeling real-world problems, the order of polynomial regression is usually set to 2nd or 3rd order to meet the needs. Let the dataset D contain n records: $\left\{t_1,t_2,t_3,\cdots,t_n\right\}$ and have d independent variables $\left\{x_1,x_2,\cdots,x_d\right\}$ and a dependent variable y.

For each record there are $t_i=(x_{i1},x_{i2},x_{i3},\cdots,x_{in},y)$ and assuming that $\sqrt{\sum_{j=1}^{d}x_{ij}^2}\le 1$, and let $g(x)=x_1^{c_1}\cdot x_2^{c_2}\cdots x_d^{c_d}$, where $c_1,c_2,c_3,\cdots,c_d\in N$, and $G_j=\left\{x_1^{k_1}\cdot x_2^{k_2}\cdots x_d^{k_d}\,\middle|\,\sum_{i=1}^{d}k_i=j\right\}$, where $0\le j\le m$, let λ_g be the $g(x)$ coefficients then the d-dimensional m-order $(d>m)$ polynomial regression model can be expressed as shown in equation (7).

The fitting of polynomial regression can be converted to multivariate linear regression treatment by variable substitution, and the multivariate linear regression model can be obtained by transforming each $g(x)$ into a new independent variable z_i through a mapping as in equation (8):

$$y=\sum_{j=1}^{m}\sum_{g\in G_j}\lambda_g g(x) \tag{7}$$

$$\begin{cases} z_1=x_1,z_2=x_2,\cdots,z_{c_d^1}=x_d \\ z_{c_d^1+1}=x_1^2,z_{c_d^1+2}=x_1x_2,\cdots,z_{c_d^1+c_d^2-1}=x_{d-1}x_d \\ z_{c_d^1+c_d^2}=x_d^2,z_{c_d^1+c_d^2+1}=x_1^3,\cdots,Z_{\sum_{i=1}^{m}c_d^i}=x_d^m \end{cases} \tag{8}$$

After mapping, it is possible to convert the polynomial regression into a multivariate linear regression on z_i, as shown in equation (9), where $\vec{\omega}$ is a vector of coefficients of z_i corresponding to the coefficients of λ_g from the polynomial regression on $g(x)$:

$$Y=Z\vec{\omega} \tag{9}$$

Let $\sigma=\sum_{i=1}^{m}C_d^i$, and its cost function can be expressed as shown in equation (10):

$$\begin{aligned} f_D(t_i,\vec{\omega})&=\sum_{i=1}^{n}f(t_i,\vec{\omega})=\sum_{i=1}^{n}(y_i-\vec{\omega}\vec{z}_i)^2 \\ &=\sum_{t_i\in D}(y_i)^2-\sum_{j=1}^{\sigma}\left(2\sum_{t_i\in D}y_iz_{ij}\right) \\ &+\sum_{1\le j,l\le\sigma}\left(\sum_{t_i\in D}z_{ij}z_{il}\right)\omega_j\omega_l \end{aligned} \tag{10}$$

The $\vec{\omega}$ can be solved by least squares:

$$\vec{\omega}=\left(Z^TZ\right)^{-1}Z^TY \tag{11}$$

In order to test the impact of urban green development path on economic growth synergy, this study uses polynomial regression and response surface analysis techniques to analyze the specific regression model is set as follows:

$$\begin{aligned} EG&=a_0+a_1UGDP+a_2UGA+a_3UGDP^2+a_4UGDP\times UGA \\ &+a_5UGA^2+a_6X+\beta+\mu+\varepsilon \end{aligned} \tag{12}$$

In Eq. (12), EG stands for economic growth synergy, $UGDP$ stands for urban green development path, UGA stands for urban green actions, X stands for control variables, β stands for time fixed effects, μ stands for urban fixed effects, and ε stands for the error term.

IV. Empirical results and analysis

This study used the econometric software Stata 15.0 to empirically analyze the relationship between urban green development paths and economic growth synergies, based on the empirical results to test the hypotheses put forward in the second chapter of this research species. Specifically, it includes descriptive statistics of variables, correlation analysis and hypothesis testing (baseline regression analysis as well as robustness test). In this paper, all variables are Zscore standardized so that they can be compared under the same magnitude.

IV. A. Descriptive statistics

Table 1 demonstrates the descriptive statistics and variance inflation factors of the main variables, including sample observations, mean, standard deviation, minimum, median, maximum, and VIF. Among them, the mean value of urban economic growth EG is 0.078, standard deviation is 0.022, median is 0.061, and maximum is 0.223, which indicates that the data concentration of the economic growth is better among cities. The mean value of Urban Green Development Path UGDP is 0.212, the standard deviation is 0.116, the median is 0.178, and the maximum value is 0.796, indicating that the level of green development paths in most cities is relatively low, and that there are some differences in green development paths among cities, but there is no excessive discrete situation. The mean value of the UGA of urban green actions is 2.026, the standard deviation is 0.532, the median is 2.115, and the maximum value is 4.158, indicating that there is no excessive dispersion in the green actions of the cities in the sample. In order to avoid inaccurate results due to multicollinearity, this study further analyzed the variance inflation factors of each variable. Except for the explanatory variables, the variance inflation factors of the remaining variables are all less than 3.8, which is far less than 10, indicating that the model in this study does not have serious multicollinearity problems and can be analyzed empirically in the next step.

Table 1: Descriptive statistics and variance expansion factors

Variables	Number	Mean	SD	Min	Median	Max	VIF
EG	20	0.078	0.022	-0.093	0.061	0.223	
UGDP	20	0.212	0.116	0.026	0.178	0.796	1.719
UGA	20	2.026	0.523	0.687	2.115	4.158	1.478
P	20	1.434	1.277	0.524	1.048	1.621	1.412
IS	20	0.057	0.626	0.018	0.043	0.075	2.233
TI	20	0.175	0.097	0.101	0.179	0.226	1.106
FDI	20	0.463	0.732	0.229	0.495	0.502	3.785

IV. B. Correlation analysis

The correlation coefficient matrix of each variable is shown in Figure 2, * indicates p<0.1, ** indicates p<0.05, and *** indicates p<0.01. The correlation coefficient between the independent variable Urban Green Development Path UGDP and Urban Economic Growth EG is 0.084 and significant at 1% level, and the correlation coefficient shows that there is a positive correlation between the Urban Green Development Path and Urban Economic Growth. The correlation coefficient between urban green action UGA and urban economic growth EG is 0.047 and significant at 10% level, and there is a positive correlation between them. There is a positive and insignificant correlation between urban green development path UGDP and urban green action UGA with a correlation coefficient of 0.035.

The control variables selected for this study are population density P, industrial structure level IS, technological innovation level TI, and openness to the outside world FDI. for Population density P, industrial structure level IS, technological innovation level TI, and openness to the outside world FDI are positively correlated with the dependent variable urban economic growth EG, with correlation coefficients of 0.492 (p<0.001), 0.695 (p <0.001), 0.461 (p<0.001), 0.596 (p<0.001). The above results show that most of the control variables selected in this paper are valid and all of them have a high level of significant impact on urban economic growth.

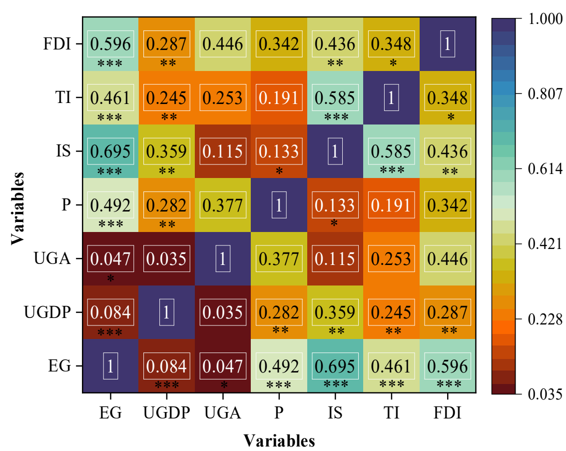

Figure 2: The correlation coefficient matrix of each variable

IV. C. Benchmark regression analysis

Since the polynomial regression model in this study incorporates the cross-multiplication terms of urban green development paths and green actions and their respective squared terms, in order to eliminate the problem of inconsistency in the quantiles of urban green development paths and green actions, the data of urban green development paths and green actions are standardized in this study. It was tested that when the cubic terms of urban green development paths and green actions were added to the model, the increase in R^2 was no longer significant, indicating that the use of a polynomial regression model with quadratic terms was appropriate. Table 2 shows the results of the model regression and response surface analysis obtained using clustered robust standard errors. In particular, models (1)-(3) are the estimation results without controlling for year and area effects, and models (4)-(6) are the estimation results with controlling for year and area effects. Models (1) and (4) are the results that only include control variables, models (2) and (5) are the estimation results after adding the primary terms of urban green development path and green action on the basis of models (1) and (4), respectively, and models (3) and (6) are the estimation results after adding the multiplication terms of urban green development path and green action and their respective square terms on the basis of models (2) and (5) respectively.

$\triangle R^2$ is significantly normal in models (2), (3), (5) and (6), indicating that the interpretability of the model is improved by adding primary and secondary terms sequentially. In the response surface analysis, the coefficients of the curvature of the inconsistency curve are all insignificantly negative (-0.003, $p > 0.1$), indicating that there is no significant difference in the impacts of urban green development paths and the consistency or inconsistency of green actions on the economic growth of the city, and that the hypothesis H1 has not been verified.

The slope of the consistency curve is significantly positive (0.004, $p < 0.05$), and the curvature is positive but not significant (0.001, $p > 0.1$), which indicates that compared to the urban green development path and green actions with low consistency, the urban green development path and green actions with high consistency have a stronger effect on the enhancement of the city's economic growth, and Hypothesis H2 is verified.

The slope of the inconsistency curve is significantly positive (0.005, $p < 0.05$), and the curvature is negative but not significant, indicating that compared to the low green development path-high green action combination, the high green development path-low green action combination has a higher enhancement effect on the city's economic growth, and Hypothesis H3 is verified.

Table 2: Model regression and response surface analysis results

	(1)	(2)	(3)	(4)	(5)	(6)
P	0.387**	0.375**	0.368**	0.377**	0.392**	0.384**
	0.029	0.028	0.029	0.029	0.028	0.029
IS	0.564***	0.568***	0.561***	0.566***	0.562***	0.567***
	0.048	0.048	0.048	0.048	0.047	0.047
TI	0.483**	0.489**	0.485**	0.484**	0.485**	0.486**
	0.043	0.043	0.043	0.043	0.043	0.043
FDI	0.283*	0.286*	0.282*	0.287*	0.287*	0.283*
	0.006	0.006	0.006	0.006	0.006	0.006
UGDP		0.025***	0.024***		0.024***	0.025***
		0.002	0.002		0.002	0.002
UGA		0.023**	0.022**		0.024**	0.023**
		0.001	0.001		0.001	0.001
$UGDP^2$			-0.002			-0.002
			0.003			0.003
UGDP* UGA			0.008**			0.008**
			0.002			0.002
UGA^2			0.007			0.007
			0.001			0.001
Constant	0.015	0.029	0.031	0.006	0.026	0.026
	0.031	0.031	0.029	0.028	0.031	0.028
Year	No	No	No	Yes	Yes	Yes
Province	No	No	No	Yes	Yes	Yes
Response surface analysis						
Consistency curve						
Gradient			0.004**			0.004**

Curvature			0.001			0.001
Inconsistent curve						
Gradient			0.005**			0.005**
Curvature			-0.003			-0.003
R^2	0.521	0.521	0.527	0.558	0.556	0.561
$\triangle R^2$		0.008***	0.007***		0.008***	0.007***
Adjusted R^2	0.512	0.517	0.518	0.528	0.534	0.535
AIC	-2405.058	-2456.215	-2427.471	-2435.339	-2461.21	-2453.058
N	20	20	20	20	20	20

IV. D. Robustness Tests

In order to further confirm the robustness and validity of the above regression results, this study mainly adopts the following two methods to carry out the robustness test: one is to test the robustness by lagging the dependent variable, and the other is to test the robustness of the above regression results by supplementing the omitted variables. The robustness test results of these two methods are basically consistent with the results analyzed above, and the specific robustness results are as follows.

IV. D. 1) Dependent variable lags

Due to the uncertainty of the timing of synergistic economic growth in the green strategy of urban development, the dependent variable in the paper uses a one-year lag in the measurement of the city's economic growth benefits, and since the process of the city's transformation of the green development path into economic benefits may be 1-2 years, a two-year lag in the city's economic growth benefits is used for the robustness test. The main effects regression results with lagged dependent variables are shown in Table 3. The results of response surface analysis in models (3) and (6) show that when the city develops green strategy and green action are consistent, the slope is significantly positive (slope = 0.005, $p<0.05$), indicating that hypothesis 2 is valid, and when the city develops green strategy and green action are inconsistent, the slope is significantly positive (slope = 0.006, $p<0.05$), indicating that hypothesis H2 is valid, and the curvature is not significantly negative (curvature = -0.002, $p > 0.1$), indicating that hypothesis H3 holds and hypothesis H1 does not. Same results as those obtained above.

IV. D. 2) Adding missing variables

When formulating economic growth targets, resource and environmental carrying capacity should be fully considered to ensure the synergistic development of urban green construction and economic growth. In this paper, resource and environmental carrying capacity is introduced as a control variable into the previous model for robustness testing, and the main effect regression results of the supplementary omitted variables are shown in Table 4. When UGDP=UGA, the curvature is not significant (curvature=0.001, $p>0.1$) and the slope is significantly positive (slope=0.007, $p<0.05$), indicating that compared with the “low green development path-low green action” mode, the city in the “high green development path-high green action” mode has a higher growth rate. When UGDP=-UGA, the slope is significantly positive (slope=0.005, $p<0.05$), indicating that compared to the “low green development path-high green action” model, cities in the “high green development path-high green action” model have higher economic growth, validating H2. “H3 is verified, as the curvature is not significantly negative (curvature = -0.003, $p>0.1$), indicating that the consistency of green development path and green action has little effect on economic growth, and hypothesis H1 is not verified. The same results as those obtained above.

IV. E. Recommendations for countermeasures

The relationship between the two is investigated above through a polynomial regression algorithm, which verifies some of the research hypotheses, and the development path of synergizing urban green building and economic growth is discussed below.

IV. E. 1) Maintaining moderate population concentrations

Moderate population agglomeration helps to transform production and lifestyles and accelerate the realization of green development. The Government should take appropriate policy measures to ensure that the population concentration of urban agglomerations remains at an appropriate level, with particular emphasis on the introduction of high-quality human resources in the process of regulation, as the generation of new technologies requires the support of high-quality human resources, and the successful experience of developed countries has proved that the accumulation of human capital is conducive to the development of a green economy.

Table 3: Main effect regression when the dependent variable lags

	(1)	(2)	(3)	(4)	(5)	(6)
P	0.358**	0.354**	0.358**	0.354**	0.352**	0.351**
	0.032	0.034	0.031	0.033	0.034	0.033
IS	0.537***	0.537***	0.532***	0.535***	0.533***	0.532***
	0.049	0.051	0.051	0.052	0.048	0.049
TI	0.511***	0.519***	0.513***	0.518***	0.514***	0.515***
	0.055	0.054	0.053	0.053	0.055	0.054
FDI	0.353*	0.356*	0.359*	0.355*	0.358*	0.355*
	0.004	0.004	0.003	0.003	0.003	0.004
UGDP		0.031**	0.029**		0.029**	0.030**
		0.002	0.002		0.002	0.002
UGA		0.027**	0.029**		0.027**	0.028**
		0.001	0.001		0.001	0.001
$UGDP^2$			-0.003			-0.003
			0.001			0.001
UGDP* UGA			0.005**			0.005**
			0.001			0.001
UGA^2			0.006			0.006
			0.002			0.002
Constant	0.032	0.033	0.032	0.035	0.034	0.035
	0.022	0.021	0.023	0.021	0.022	0.022
Year	No	No	No	Yes	Yes	Yes
Province	No	No	No	Yes	Yes	Yes
Response surface analysis						
Consistency curve						
Gradient			0.005**			0.005**
Curvature			0.002			0.002
Inconsistent curve						
Gradient			0.006**			0.006**
Curvature			-0.002			-0.002
R^2	0.539	0.534	0.538	0.535	0.531	0.537
$\triangle R^2$		0.006***	0.007***		0.006***	0.007***
Adjusted R^2	0.0523	0.519	0.524	0.522	0.523	0.513
AIC	-2485.712	-2428.151	-2445.521	-2449.905	-2492.959	-2462.077
N	20	20	20	20	20	20

IV. E. 2) Optimizing and upgrading the industrial structure

Adjusting and optimizing the industrial structure and promoting the supply-side structural reform is the key work of urban development should choose green, low-carbon, recycling modern service industry and high-tech industry as the direction of industrial development, at the same time, the government should also strongly support the green credit, encourage enterprises to make green investment, and accelerate the transformation and upgrading of industrial structure.

IV. E. 3) Innovation-driven green development

Innovation is the first driving force for development and the fundamental driving force for realizing green development. Innovation requires both conceptual innovation and technological innovation. Conceptual innovation means that the development concept of polluting first and then treating later has been eliminated and needs to be replaced by a new development concept. The government should set up the concept of green development, promote green civilization, so that the concept of green development is deeply rooted in people's hearts, and encourage the masses to green consumption and enterprises to green production. Strengthening technological innovation, especially green technological innovation, is the only way to realize a win-win situation between economic growth and environmental protection. Increased investment in R&D by enterprises can improve the level of technological innovation, promote enterprises to build a green, low-carbon and recyclable production system, and promote the process of green development. Therefore, the government should give full play to its functions, encourage and support enterprises to carry out green technological innovation, and accelerate the construction of a market-oriented green technological innovation system.

Table 4: Main effect regression when added missing variables

	(1)	(2)	(3)	(4)	(5)	(6)
P	0.339**	0.337**	0.336**	0.335**	0.336**	0.336**
	0.021	0.023	0.026	0.027	0.021	0.025
IS	0.534***	0.538***	0.536***	0.537***	0.533***	0.535***
	0.023	0.027	0.025	0.026	0.023	0.025
TI	0.497***	0.492***	0.491***	0.493***	0.498***	0.495***
	0.046	0.046	0.041	0.043	0.041	0.042
FDI	0.353*	0.354*	0.356*	0.355*	0.352*	0.357*
	0.027	0.025	0.024	0.021	0.023	0.026
UGDP		0.036**	0.034**		0.032**	0.038**
		0.003	0.002		0.003	0.002
UGA		0.032**	0.032**		0.031**	0.030**
		0.002	0.002		0.003	0.002
$UGDP^2$			-0.004			-0.004
			0.002			0.002
UGDP* UGA			0.006**			0.006**
			0.003			0.003
UGA^2			0.005			0.005
			0.001			0.001
Constant	0.028	0.027	0.028	0.026	0.025	0.027
	0.017	0.015	0.016	0.016	0.014	0.016
Year	No	No	No	Yes	Yes	Yes
Province	No	No	No	Yes	Yes	Yes
Response surface analysis						
Consistency curve						
Gradient			0.007**			0.007**
Curvature			0.001			0.001
Inconsistent curve						
Gradient			0.005**			0.005**
Curvature			-0.003			-0.003
R^2	0.605	0.602	0.604	0.608	0.609	0.609
$\triangle R^2$		0.005***	0.006***		0.005***	0.006***
Adjusted R^2	0.588	0.584	0.586	0.592	0.589	0.582
AIC	-2412.769	-2454.654	-2428.918	-2432.317	-2474.139	-2450.572
N	20	20	20	20	20	20

IV. E. 4) Enhancing quality external cooperation

The government should endeavor to increase the scale of investment, actively introduce high and new technologies and management models while strengthening self-digestion, absorption and re-innovation, and improve the capacity for independent innovation. At the same time, it should emphasize the screening of the quality of foreign-funded enterprises and pursue high-quality foreign cooperation. In addition, the government should vigorously combine the “Belt and Road” initiative to increase foreign investment in strategic emerging industries, high value-added industries and other fields, and move toward a higher level of foreign cooperation to strengthen the openness to the outside world to promote the driving role of green development.

V. Conclusion

Studying the dynamic relationship between urban green development and economic growth is of great significance for cities to realize the win-win situation of economic growth and green development. This paper explores the relationship between urban green development path, green action and economic growth synergy using polynomial regression algorithm with urban green development path as the independent variable, and thus puts forward countermeasure suggestions. The research results are as follows:

The slope of the consistency curve is significantly positive at the 5% level, and the curvature is positive but not significant, indicating that when urban green development path and green action are consistent at a low level, they do not have as great an effect on economic growth as when they are consistent at a high level. The slope of the inconsistency curve is significantly positive at the 5% level, indicating that the high green development path-low green action combination promotes more synergistic economic growth than the low green development path-high green action combination, and the curvature is negative but not significant, indicating that the consistency of the urban green development path and the green action does not necessarily result in higher economic growth benefits. Therefore, research hypotheses H2 and H3 were verified and H1 was not verified.

Urban green development plays an important role in the process of economic growth, in order to synergize urban green development and economic growth, from four perspectives of population aggregation, industrial structure, technological innovation and opening up to the outside world, we put forward the suggestions of maintaining moderate population aggregation, optimizing and upgrading the industrial structure, innovation-driven green development, and strengthening high-quality opening up and cooperation with the outside world in the hope of enhancing the level of economic growth and green development of each city.

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