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Empirical Study on the Driving Force of Urban Utility Tunnel Development

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Abstract

Urban utility tunnel has been regarded as an important symbol of urban modernization, so it is important to understand the quantized relationship between city development and urban utility tunnel for city management and policy making. In this study, the internal relationship between the development amount of urban utility tunnel and urban population density was discussed, as well as urban GDP per capita, urban construction land area per capita and urban land price index, based on the IBM SPSS platform, through adopting the development amount of urban utility tunnel and the urban development data of the past 46 years of Japan. It was shown that the correlation relationship of the development amount of urban utility tunnel with the density of urban population was comparatively strong negative, and relatively strong positive, comparatively strong positive, relatively strong negative for GDP per capita, urban construction land area per capita and urban land price index respectively, which explained the driving effect that urban development imposed on urban utility tunnel construction in essence. Furthermore, a quantitative model was proposed for the relationship between the development amount of urban utility tunnel and urban development indexes, and the model could be a reference for decision making of urban utility tunnel development in China and other countries.

Keywords: Urban Utility Tunnel; Influential Factors; Correlation Research; Regression Research.

1. Introduction

Throughout the centuries, urban utility tunnel has been regarded as an important symbol of urban modernization, and also be an inevitable product of city development, which has been proved by the development history and experience of developed countries [1-10]. Systematic research has been carried out with a variety of engineering practices [11-14]. It leaded to the establishment of reasonable design, planning, financing and standard systems which has been worked out successfully in the mass construction of their own countries [11-15]. Behind the blossoming phenomenon, it is necessary for city management officials and practitioners related to better understand the relationship between city development and urban utility tunnel in a correct and rational way.

Japan perhaps owns the most advanced technology and the most complete scheme and laws for utility tunnels in the world. The first utility tunnel in Japan was built in 1926 in Chiyoda, Tokyo with power cable, telecom, water supply and gas pipelines incorporated. Urban utility tunnel construction in Japan had little further progress until the 1950-1960s. Then the Japanese government started to develop utility tunnels rapidly at the same time as its road construction program (see Figure 2) [16-18].

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The utility tunnels law was set out in 1963 and up to now, there are a lot of utility tunnels in more than 80 Japanese cities such as Tokyo, Osaka, Nagoya, etc. [16-19]. In order to make clear the connotative meaning of developing urban utility tunnel, it is advisable to give an insight into Japan's experience.

This study adopted the development amount of urban utility tunnel and the urban development data of the past 46 years of Japan (years of 1965-2010), to analyze the correlation of development amount of urban utility tunnel with urban economy, social, environment, population and land exploitation etc., then, to specify the internal relationship between the development of urban utility tunnel and its influence factors, furthermore, to propose a quantitative model for this relationship by regression method. As a consequence, the driving force and the essential implication of urban utility tunnel development could be understood. The flowchart of this research methodology was shown Figure 1.

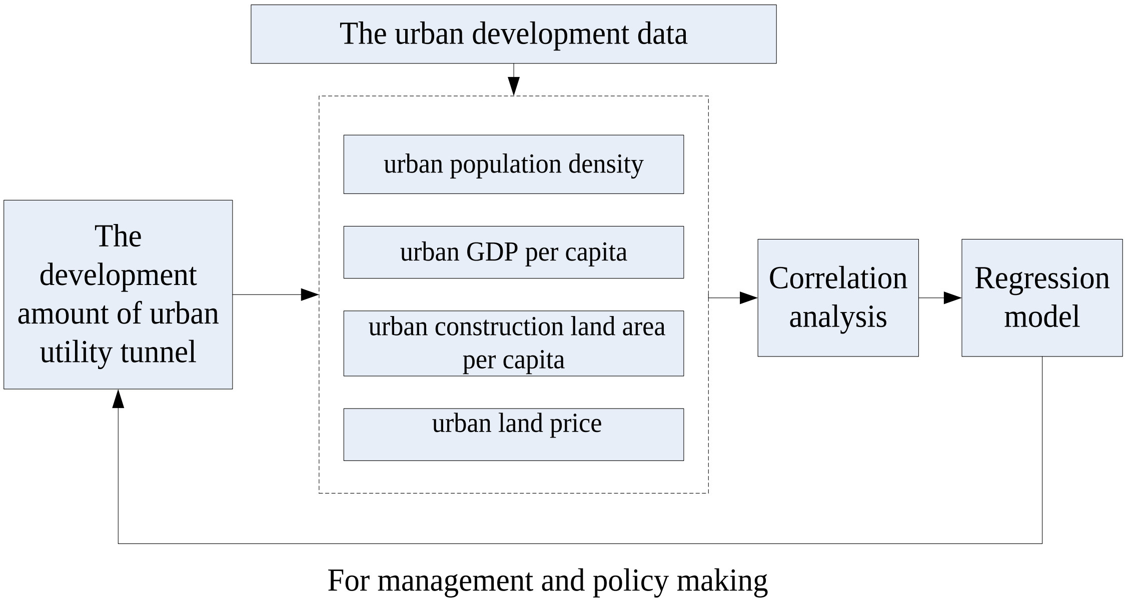

Figure 1. The flowchart of the methodology

2. The Main Indexes Selected

In this study, four indexes of urban population density, urban GDP per capita, urban construction land area per capita and urban land price were selected to present the level of urban economic development, of urbanization, of social development and environmental condition of the interested country respectively. Among them, urban population density reflects urban population, the level of urbanization, the environmental pressure and the situation of urban society; urban GDP per capita corresponds to the level of urban economic development and the situation of urban society; urban construction land area per capita is a mirror of the scale of urban construction, the urban landscape and the urban ecological environment; urban land price implies the levels of urban economy, population and social development.

3. Data Source

The data of the amount of urban utility tunnel development of each year in Japan were obtained from the references [16-19], in which these official statistical data were done by the Japan Tunnelling Association. In the three original literatures, the curve of development amounts versus years was plotted, and the data points corresponding to each year were extracted from the curve; the data of population density, GDP per capita, construction land area per capita and land price were collected from the Websites of Statistics Bureau of General Affairs Ministry of Japan(http://www.stat.go.jp), of Land, Infrastructure and Transport of Japan(http://www.mlit.go.jp), of Institute of Real Estate Research of Japan(http://www.reinet.or.jp/en) and of the Japanese government(http://www.gov-book.or.jp) respectively. These statistical data were officially published by the Japanese government and its affiliated research institutes related. Due to the rather large span of years, some of the official websites only provide the data of certain years, so that many data sources issued by the Japan government were gathered.

4. Data Analysis

In order to intuitively present data and analyze them conveniently, the data were defined by applying the function of 'figure-multi-lines' provided by IBM SPSS (Statistical Packages for Social Science) platform, and their change trends with years were shown in Figure 2. As seen, from 1965 to 2010, the total amount of urban utility tunnel constructed in Japan increased linearly, especially, the growth rate increased significantly after the year of 1989. As far as the four factors were concerned, the population density increased all the time, but the growth rate slowed down and even present a convergent tendency since 1985, which was mainly affected by the low birthrate and late marriage and late childbirth occurred in Japan [20]; GDP per capita rapidly grew before 1990, and after, the growth rate generally decelerated in fluctuation, reflecting the slow economic development in Japan in recent years; construction land area per capita always increased with years, but with the passage of time, it only present slow growth rate but not any convergent tendency, indicating the progressive enlargement of urban size; the land price in 2000 was chosen as benchmark land price and assigned a value of 100, as seen in the figure, the land price had a global increasing trend before 1991, however, it gradually declined after that, as a consequence of the financial crisis suffered in 1990 in Japan, which had a strong impact on the entire society and economic development and on the real estate further [21].

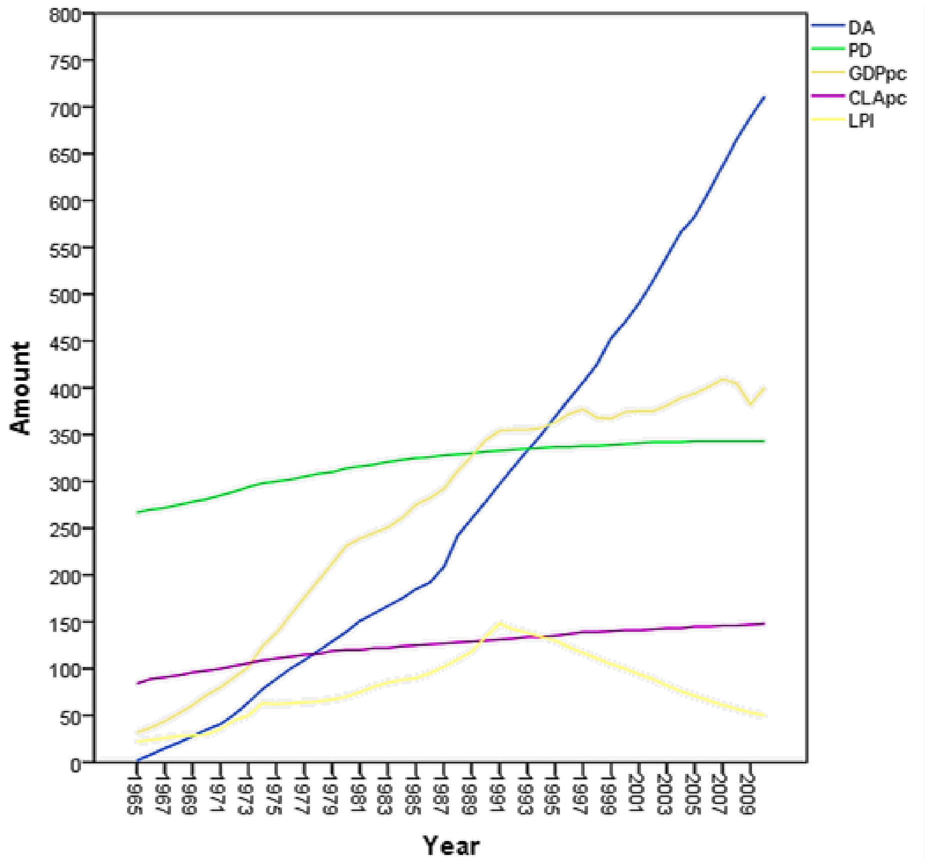

Figure 2. The relation curves between year and the development amount

5. The Regression Model

A lot of mathematic curve (e.g. power function, logarithmic function and exponential function etc.) in the theory of statistics as well as bivariate logistic and multiple logistic regression were applied on establishing the prediction model, but it seemed that their characteristics did not match the data collected so that the deviations were too large to be acceptable. According to comprehensive analysis and estimation, multiple linear regression method was picked up to express the quantitative relationship of amount of urban utility tunnel development with the influence factors as Equation 1:

$$DA = \beta_0 + \beta_1 PD + \beta_2 GDPpc + \beta_3 CLApc + \beta_4 LPI \tag{1}$$

Where;

DA is the development amount of urban utility tunnel, in km;

PD stands for population density, in person/ km^2;

GDPpc is GDP per capita, in billions of yen/ (person·year)

CLApc is construction land area per capita, in m^2/person;

LPI is land price index, dimensionless;

And $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are parameters.

6. Correlation Analyses

6.1. Scatter Diagram

It can be seen from Figure 3, for one thing, the development amount of urban utility tunnel displayed noticeable linear correlation with population density, GDP per capita and construction land area per capita; for another thing, the similar relationship was shown between construction land area per capita and population density, GDP per capita and population density, construction land area per capita and GDP per capita respectively. On the contrary, the land price index had a weak linear correlation with all four indexes of development amount, population density, GDP per capita and construction land area per capita. Therefore, in order to clarify the degree of their connection, a further correlation analysis would be done below.

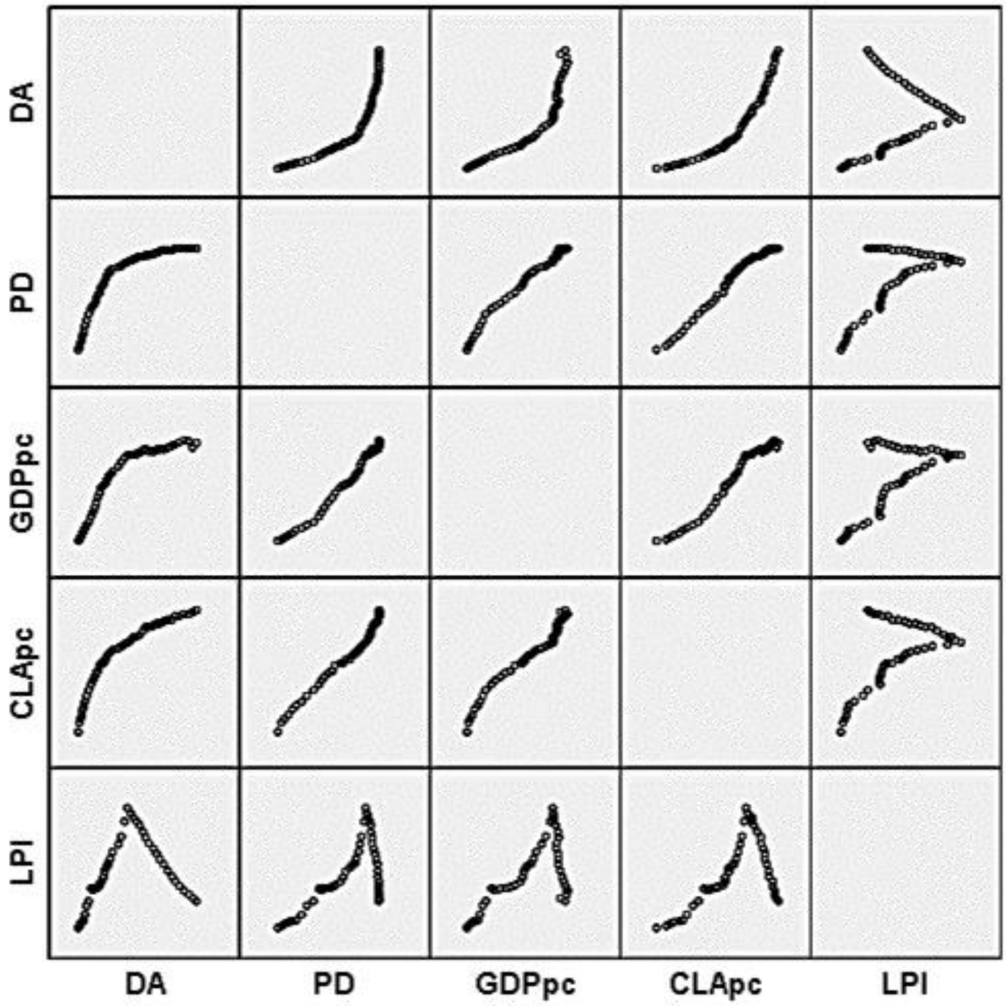

Figure 3. Scatter diagram of variables for correlation analysis

6.2. Analyses of Correlation and Partial Correlation

The results of correlation and partial correlation analyses for all variables were displayed in Table 1, in which, the development amount had remarkable statistical correlation with population density, GDP per capita, construction land area per capita and land price index, since the coefficients of their partial correlation were -0.691, 0.784, 0.610, -0.548 respectively. In the same manner, population density and GDP per capita and construction land area per capita as well as GDP per capita and land price index also had noticeable correlation ships, because the coefficients of their partial correlation were 0.640, 0.899 and 0.579 respectively, furthermore, the 2-tailed significances of all parameters above were less than 0.01. In addition, there was a little correlation between GDP per capita and construction land area per capita, with a 2-tailed significance larger than 0.01 but less than 0.05; finally, both population density and construction land area per capita did not have correlation ships with land price index, since the 2-tailed significances were 0.649 and 0.148 and larger than 0.05.

Table 1. The results of variable correlation and partial correlation analyses

Variables		Development amount		Population Density		GDP per capita		Construction land area per capita		Land price index	
		Correlation	Partial correlation	Correlation	Partial correlation	Correlation	Partial correlation	Correlation	Partial correlation	Correlation	Partial correlation
Development amount	Pearson correlation										
	Sig.(2-tailed)										
	N (df)										
Population Density	Pearson correlation	$.870^{**}$	-0.691								
	Sig.（2-tailed）	0.000	0.000								
	N (df)	46	41								
GDP per capita	Pearson correlation	0.896^{**}	0.784	0.992^{**}	0.640						
	Sig.(2-tailed)	0.000	0.000	0.000	0.000						
	N(df)	46	41	46	41						
Construction land area per capita	Pearson correlation	0.922^{**}	0.610	0.990^{**}	0.899	0.985^{**}	0.307				
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.045				
	N(df)	46	41	46	41	46	41				
Land price index	Pearson correlation	0.342^{*}	-0.548	0.703^{**}	0.071	0.695^{**}	0.579	0.610^{**}	-0.224		
	Sig. (2-tailed)	0.000	0.000	0.000	0.649	0.000	0.000	0.000	0.148		
	N(df)	46	41	46	41	46	41	46	41		

** Significant correlation at the level of 0.01(2-tailed); * Significant correlation at the level of 0.05(2-tailed)

7. Regression Analyses

7.1. Regression Model

On the basis of the correlation analyses in the previous section, the data of 1965 to 2010 were utilized to determine the quantitative relation between the amount of urban utility tunnel development and the influence factors by multiple linear regression method. In this way, those unknown coefficients in formula (1) were calculated and the regression results were listed in Table 2, where the P values of all variables were 0.000 and less than 0.01. As usual, the quality of this regression was measured by R^2, whose values were shown in Table 3, where the values of R, R^2 and adjusted R^2 were 0.988, 0.976 and 0.974 respectively, indicating a satisfactory regression with very few discreteness. Moreover, the usage of the four indexes of population density, GDP per capita, construction land area per capita and land price was effective for demonstrating the variability of 97.4% for the development amount of utility tunnel. In addition, the results of residual analysis were plotted in Figures 4 and 5, which illustrated that the random errors followed the normal distribution without abnormal values. Consequently, the quantitative model among the development amount of urban utility tunnel and population density, GDP per capita, construction land area per capita and land price could be expressed as Equation 2:

$$DA = -18.548PD + 2.726GDPpc + 18.731CLApc - 1.622LPI + 3278.494 \tag{2}$$

Table 2. Coefficients of the regression model

Models		Non-standardized Coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation			
1	Constant	3278.494	562.515		5.828	0.000
	Population density	-18.548	3.028	-2.076	-6.125	0.000
	GDP per capita	2.726	0.337	1.598	8.093	0.000
	Construction land area per capita	18.731	3.799	1.563	4.930	0.000
	Land price index	-1.622	0.386	-0.264	-4.199	0.000

a. dependent variable: development amount

Table 3. The results of error analyses

R	R^2	Adjusted R^2	Estimated errors
0.988 [a]	0.976	0.974	34.530

a. predicted variables: constant, population density, GDP per capita, construction land area per capita and land price index

b. dependent variable: development amount

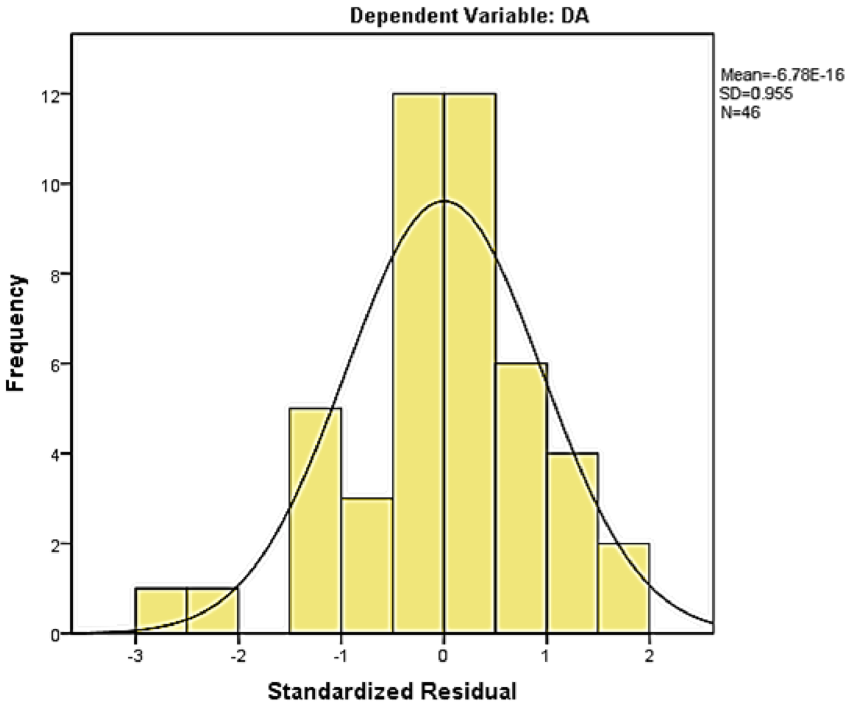

Figure 4. The histogram of standardized residuals for development amount

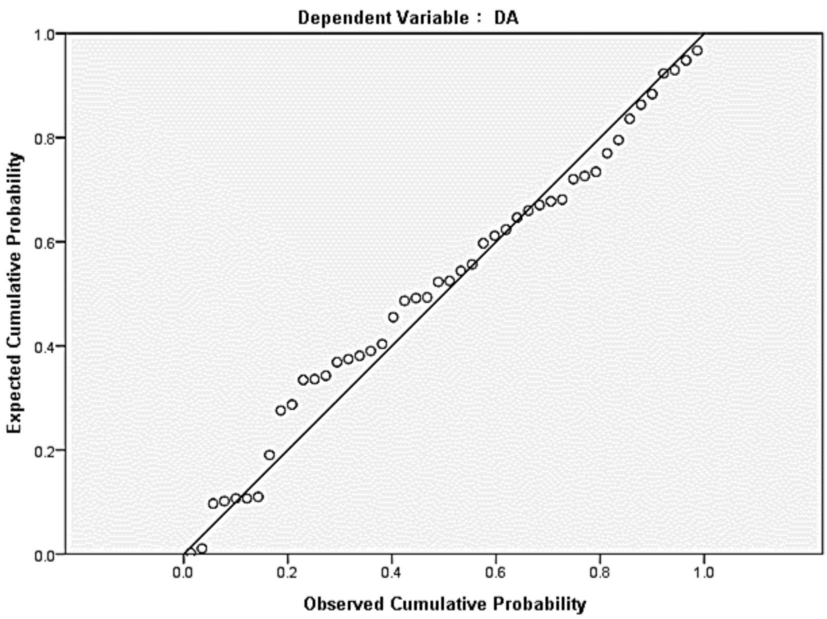

Figure 5. Standard P-P figure of standardized residual

7.2. Stepwise Regression Analysis

With regard to the quantitative model (i.e. expression (2)) proposed above, it was necessary to confirm whether it had been the most optimal one and sufficient to describe the driving force relationship between urban utility tunnel development and the four indexes of urban development. For this reason, a stepwise regression analysis was carried out to make these doubts clear. On the IBM SPSS platform, the function of 'Use F Value' was used for the entry and/or removal of independent variables. In this paper, a value of 3.84 was set for the entry of F-Value and 2.71 for the removal of F-Value. It could be seen from Table 5, the 4th model was the most optimal one, since the corresponding R^2 and adjusted R^2 were 0.976 and 0.974 respectively, being the largest one in each column. Meanwhile, all P values in Table 4 were equal to 0.000, implying the significance testing for each model was positive. As a result, the expression (2) was the best regression model.

Table 4. Coefficient of stepwise regression model

Models		Non-standardized coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation			
1	Constant	-1094.950	88.032		-12.438	.000
	Construction land area per capita	11.045	0.700	0.922	15.769	.000
2	constant	1714.528	372.235		4.606	.000
	Construction land area per capita	35.237	3.200	2.941	11.013	.000
	Population density	-18.226	2.385	-2.040	-7.641	.000
3	Constant	4609.121	549.083		8.394	.000
	Construction land area per capita	32.183	2.412	2.686	13.341	.000
	Population density	-28.027	2.385	-3.137	-11.752	.000
	GDP per capita	2.321	0.381	1.361	6.087	.000
4	Constant	3278.494	562.515		5.828	.000
	Construction land area per capita	18.731	3.799	1.563	4.930	.000
	Population density	-18.548	3.028	-2.076	-6.125	.000
	GDP per capita	2.726	0.337	1.598	8.093	.000
	Land price index	-1.622	0.386	-.264	-4.199	.000

a. dependent variable: development amount

Table 5. Error analyses of stepwise regression models

Models	R	R^2	Adjusted R^2	Estimated errors
1	0.922[a]	0.850	0.846	83.967
2	0.968[b]	0.936	0.933	55.316
3	0.983[c]	0.966	0.964	40.797
4	0.988[d]	0.976	0.974	34.530

a. Predicted variables: constant, construction land area per capita;

b. Predicted variables: constant, construction land area per capita, population density;

c. Predicted variables: constant, construction land area per capita, population density, GDP per capita;

d. Predicted variables: constant, construction land area per capita, population density, GDP per capita, land price index;

e. Dependent variable: development amount.

8. Discussion on the Influence Factors for the Driving Force of Urban Utility Tunnel Development

8.1. Influence Factors

(1) Population density

According to the analysis in section 6, there was a relatively strong negative correlation between the development amount of urban utility tunnel and urban population density, in other words, when the population density decreased, it was still possible for the development amount of urban utility tunnel to increase, which contradicted with the general knowledge. In this case of study, it might be caused by the correlation ships and multi-linearity between the population density and other indexes, so that the data were ‘interfered’.

(2) GDP per capita

From the regression of the expression (2) and stepwise regression analysis above, it could be seen that a comparatively strong positive correlation ship existed between GDP per capita and the development amount of urban utility tunnel. Generally, GDP per capita somehow represent the level of economic development of a city, therefore, the results of this study indicated that the development amount of urban utility tunnel closely connected to economic development, and with the increasing of the latter, the developing requirement also increased.

(3) Construction land area per capita

Usually, construction land area per capita represents the scale of a city and the storage of its urban land. As long as construction land area per capita had a strong positive correlation ship with the development amount of urban utility tunnel, then a correlation consequently consist between the shortage extent of urban land use and the development amount of urban utility tunnel.

(4) Land price index

As shown in Figure 2, the land price index increased in fluctuation before 1991, then, it present a tendency of decreasing, and probably because of which, the land price index had a relatively weak correlation ships with other influence factors(see Table 1). However, the strongly negative correlation between the development amount of urban utility tunnel and the land price index pointed out that increase of the former and decrease of the latter could appear at the same time. It was notable that the land price index was a ratio and it could be different when choosing different fiducial value as reference. Hence, if expression 2 is used to evaluate the demand of urban utility tunnel of a city/region, the reality of this city/region should be taken into account to make decision with caution.

8.2. Regression Model

The multiple linear regression model proposed in this paper has demonstrated the quantitative relationships among the development amount of urban utility tunnel and population density, GDP per capita, construction land area per capita and land price index, and also explained to which extent these four influence indexes affected the development amount, namely elaborated the effect of city development on the development of urban utility tunnel as a driving force. The expression (2) could be taken as a reference to predict the demand of utility tunnel of China as well as the estimation and correlation analysis gotten from this model would be background information for city managers to do policy making of urban utility tunnel in China.

The fact should be taken into account that all data used in this study were collected from Japan, so that the following points are noticeable when the expression (2) is used to do prediction for urban utility tunnel: ① The unit of GDP used in expression (2) was billions of yen/(person year), while the unit of CNY or USD is usually used in the statistical data of China, accordingly, the exchange rate should be paid attention when determining the magnitude of GDP per capita; ② The determination of benchmark land price is needed since land price index is a ratio actually, the assigned value of benchmark land price was 100 in expression (2), taking the land price of 2000 as a reference, thereby, the benchmark land price of the same year in China could be adopted to do some transfer for the application of this model; ③ The unit conversion of statistic data of each category is necessary, to keep the data collected from different countries in the same magnitude. ④ The regression coefficients of population density and construction land area per capita were larger whereas those of GDP per capita and land price were smaller, which meant the reality and accuracy of population density and construction land area per capita would certainly contribute to the final results. ⑤ The calculated results in this paper could be a reference to the development scale of urban utility tunnel, and should be combined with municipal planning of underground space planning to make more specific and detailed scheme for key areas.

9. Conclusion

By taking advantage of the statistic data of the urban utility tunnel development of the past 46 years of Japan as well as IBM SPSS platform, this study revealed the internal relationship between the development amount of urban utility tunnel and population density, GDP per capita, construction land area per capita and land price index in Japan respectively, and got the following conclusions: the correlation relationship of the development amount of urban utility tunnel with the density of urban population was comparatively strong negative, and relatively strong positive, comparatively strong positive, relatively strong negative for GDP per capita, urban construction land area per capita and urban land price index respectively, elaborating the effect of city development on the development of urban utility tunnel as a driving force. Furthermore, a quantitative model was proposed, which could be a reference to do policy making of urban utility tunnel development.

10. Funding

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11. Conflicts of Interest

The authors declare no conflict of interest.

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