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A new algorithm of multivariate regression analysis based on principle of least square method

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Abstract. In literature [1] and literature [2], multivariate regression analysis based on of principle least square method were lack of containing phase explained variable, in order to improve the accuracy of analytical algorithm for technical progress promotion and influencing factors under the safety regulation of enterprises, an analytical algorithm based on multivariate regression analysis is proposed. Firstly, research the analytical algorithm model of technical progress promotion and influencing factors under the safety regulation of enterprises, construct a dynamic regression model which contains lag phase explained variable, to measure the directly influences of safety regulation on technology innovation of manufacturing industry; secondly, introduce the SPSS multivariate regression analysis algorithm, using the principle of least square method to establish the multiple linear regression model, to realize the promotion of accuracy of the technology influencing factors analysis algorithm; finally, verify the effectiveness of the algorithm through simulation experiment.

Key words. Safety regulation, SPSS analysis, Multivariate regression, Technology influ-ence
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1. Introduction

The safety production of enterprise has become an important problem which seriously threatens the human survival. With the development of economy and the advancement of industrialization process, the scale of enterprises is becoming larger and larger[3, 4]. In 2012, on the ranking list of the Annual Global Enterprise Production Safety Performance Index (EPI) jointly launched by Yale University and Columbia University, the composite scores of China in 132 countries ranked the No. 116, which not only reflects the severity degree of safety production in Chinese enterprises, but also reflects the relatively weak strength of safety regulation. Therefore,

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it is an inevitable choice to strengthen the safety regulation for China. However, China is still a developing country, while changing the economic development mode, it is necessary to achieve the coordinated development of safety regulation and technological innovation through strengthening the safety production protection of enterprise[5]. Technological innovation is the decisive factor to achieve the "win-win" goal of safety production protection of enterprise and economic development. So, is this influence the positive "compensation effect" or negative "offset effect"? Scholars hold different opinions.

The traditional neo-classical theory thinks that the safety production protection of enterprise will improve the overall welfare of the enterprise, but it must reduce the technological innovation ability of enterprise at the cost of increasing the production cost. A large number of literatures show that, from the static point of view, under the assumption of fixed enterprise technology level, production process and consumption demand, the safety production regulation of enterprise is not conducive to the technological innovation of enterprise[6–8]. The economic cost caused by safety production protection of enterprise causes is excessively high, which seriously hinders the improvement of the productivity level of manufacturer and the competitiveness in international market[9]. In contrast, the scholars put forward the proposition of defending the security from the dynamic angle; they point out that the safety regulation improves the production cost of enterprise, meanwhile, it also stimulates the technological innovation of enterprise in a certain degree, so as to put forward the famous "Porter Hypothesis". In China, the research on safety regulation and technological innovation is relatively late, and most of the existing researches are analyzed from the macroscopic angle[10]. A large number of literatures using the panel data analysis of different regions in China show that there is a "U" relationship between safety regulation and technological innovation of enterprise. Some scholars have measured and calculated the inflection point of optimal safety regulation strength in various industries from the perspective of productivity, it can be found that the safety regulation strength of severe enterprises is reasonable, and can promote the industrial technological innovation and improvement of efficiency; the safety regulation of moderate and mild industry is weak, and there is a "U" relationship with technological innovation.

In literature [1] and literature [2], multivariate regression analysis based on of principle least square method were proposed. They were lack of containing phase explained variable, which makes the accuracy of prediction and evaluation not accurate enough, and their scope of application is very limited. For example, literature 3, the author applies it to spectral analysis. So far, it has not been applied to the enterprise management model. Objectively speaking, the existing literatures analyze the effect of security regulation on technological innovation from different angles, which provides a reference for the writing thought of this paper. However, technological innovation is a process of multi-factor interaction, which is affected by innovation input, infrastructure of R&D, system and culture and other factors. This paper introduces the SPSS multivariate regression analysis algorithm, and using the principle of least square method to establish the multiple linear regression model, to realize the promotion of accuracy of the technology influencing factors analysis algorithm.

2. Analytical model

2.1. Model construction and data sources

This paper constructs a dynamic regression model which contains lag phase explained variable to measure the direct effect of safety regulation on the technological innovation of manufacturing industry, the specific measurement model is as follow:

$$R\&D_{i,t} = \beta_0 + \beta_1 ERS_{i,t} + \beta_2 R\&D_{i,t-1} + \psi X + \bar{\varepsilon}_{it}\,. \tag{1}$$

Where, $R\&D_{i,t}$ is the R&D investment in phase$t$ of industry i, measuring its ability of technological innovation; $ERS_{i,t}$ is the security risk strength in phase t of industry i, the strength value of security risk is greater, which means the amount of security risk is greater, and more need to take strict measures of safety regulation. X variable is composed of FDI, enterprise scale, profit margin, human capital and other variables.

At the same time, in order to analyze the indirect effects of safety regulation on technological innovation of enterprises, this paper constructs the interaction term of safety regulation and FDI, enterprise scale, profit margin, human capital and other variables taking as the influencing factor of technological innovation, and construct the indirect effect model:

$$\begin{aligned} R\&D_{i,t} = \beta_0 + \beta_1 EFDI_{i,t} + \beta_2 ESIZE_{i,t} + \\ + \beta_4 EWAGE_{i,t} + \beta_5 R\&D_{i,t-1} + \tilde{\varepsilon}_{it}\,. \end{aligned} \tag{2}$$

Where, $EFDI_{i,t}$ indicates the interaction term of security risk strength in phase t of industry i and FDI; $ESIZE_{i,t}$ indicates the interaction term of security regulation and enterprise scale; $EWAGE_{i,t}$ indicates the interaction term of security regulation and human capital level of enterprise.

The error term $\tilde{\varepsilon}_{it} = V_i + \varepsilon_{it}$ in formula (1) and (2), because $R\&D_{i,t}$ is the function V_i, and $R\&D_{i,t-1}$ is also the function of V_i, the explanatory variable $R\&D_{i,t-1}$ in model associated is related to V_i, and X is related to V_i, namely $Cov\,(X, V_i) \neq 0$, indicating that there is correlation between explanatory variable and error term. If the regression analysis is carried out directly on equation, the obtained regression results are not only biased, but also inconsistent. When there is a correlation between explanatory variable and error item, the method of enlarging the sample size and introducing the instrumental variables can be used to solve the autocorrelation and endogenous problems in the process of panel regression. In the specific analysis process, the instrumental variables with multi choice is the lag term of weak exogenous variables, eliminating the individual effects of variables by the further first order difference of weak exogenous variables, to obtain the consistency estimation results. However, considering the first order difference is difficult to completely eliminate the autocorrelation between explained variables and residual terms, this paper uses the dynamic GMM method to carry out the regression analysis on the model in empirical analysis. Through introducing the lagged weak instrumental variables, and a set of lagged explained variables in difference equation, the dynamic GMM effectively overcome the biased regression results caused by autocorrelation.

2.2. Variable selection

(1) Explained variables: technological innovation (R&D). The measurement of technological innovation and the establishment of indexes are related to the understanding of people on the process of innovation. In the 1960s, many researchers regarded innovation as a linear process of research, development, production and sales. According to this mode, the level of innovation activity depends on the level of innovation input, that is, the level of R&D and the number of researchers. For this reason, many scholars take the R&D input level and the number of researchers as the index to measure innovation ability. Taking into account the availability of indexes, this paper adopts R&D investment funds of various industries as the index to measure innovation ability, the more R&D investment funds is, the stronger technological innovation ability of enterprises.

(2) Safety regulation (ERS). It is difficult to obtain the direct data about the safety regulation measures in the existing statistical data. The first is to use quantitative indexes to measure the strength of safety regulation. The more used method in which is: taking the GDP per capita as surrogate index of safety regulation, that is with the gradual rising of income level, the safety regulation becomes more strict; taking the security risk strength of different material as the index to measure safety regulation strength of an enterprise, namely the higher security risk strength is, the more strict safety regulation measures become; taking the quantitative index of enterprise's safety production cost of governance as an alternative variable; taking the governance facilities operating costs to measure. The second is to use the condition of being standard for enterprise's safety production governance cost, subsidy policy of enterprise's safety production and other qualitative indexes to reflect the process of enterprise's safety production protection and protection measures taken by enterprises. This paper considers the different nature of the industry, many indexes on the statistical yearbook lack of comparability between different industries, the relevant indexes must be standardized. Therefore, this paper uses the method of standardized linear to process the safety regulation indexes, construct the index system for regulation strength of different industries and its change with comprehensive reflection, measure and calculate the security risk strength of each industry as the alternative index of safety regulation, in general, the higher security risk strength in an area is, the more strict safety regulation measures in the area is. After collecting the amount of security risk of production data and the industrial output value of each industry, to calculate the security risk value for unit output value of main object in each industry, then and settle it by the way of weighted average, so as to obtain the strength of security risk.

Specific treatment is as follows: the first is to linearly standardize the amount of unit security risk in each industry.

$$UE'_{ij} = [UE_{ij} - \min(UE_j)\,]/]\max(UE_j) - \min(UE_j)]\,. \tag{3}$$

Where, UE_{ij} is the amount of security risk for unit production value of object j in industry i, $\max(UE_j)$ and $\min(UE_j)$ respectively are the maximum and minimum value of all industries, UE'_{ij} is the standardized value of index.

The second is to calculate the adjustment coefficient (W_j) of each index. Because of the different nature of different industries, the "three wastes" of the industry has a large difference in the proportion of the security risk, even if the same industry, the security risk strength of different objects has a big difference. The adjustment coefficient can be used to approximately reflect the difference of this characteristic. The method of taking value is as follow:

$$\begin{aligned} W_j &= \frac{E_{ij}}{\sum_{i=1}^m E_{ij}} \Big/ \frac{O_i}{\sum_{i=1}^m O_i} = \frac{E_{ij}}{O_i} \times \frac{\sum_{i=1}^m O_i}{\sum_{i=1}^m E_{ij}} \\ &= \frac{E_{ij}}{O_i} \Big/ \frac{\sum_{i=1}^m E_{ij}}{\sum_{i=1}^m O_i} = UE_{ij}/E\,(UE_{ij}) \end{aligned} \tag{4}$$

Where, E_{ij} is the amount of security risk of object j in industry i; $\frac{E_{ij}}{\sum_{i=1}^m E_{ij}}$ is the proportion of the amount of security risk of object j in industry i of all industries; O_i is the production value of industry i; $\frac{O_i}{\sum_{i=1}^m O_i}$ is the proportion of the production value in industry i of all industries; Conversion to: the ratio between UE_{ij} the amount of security risk for unit production value of object j in industry i and $E\,(UE_{ij})$ the industry average level of unit output value security risk of object j. After calculating the index weight of each year, then the average value during the sample period can be calculated. The third is to calculate the safety regulation of each index and the total safety regulation through the standardized value and the average weight of each single index:

$$S_i = \frac{1}{n}\sum_{j=1}^{n} W_j UE'_{ij},\, ERS = \sum_{i=1}^{P} S_i\,. \tag{5}$$

3. Multivariate regression analysis principle and SPSS

3.1. Mathematical principle of multivariate regression analysis

In real life, people often need to carry out a statistical analysis of a dependent variable, but the independent variable influencing the dependent variable is often more than 1. For example, when considering the relationship between k independent variables $X_1, X_2, \cdots, X_k$ and dependent variable y, the multiple linear regression model established by using the principle of least square method is as follow:

$$y = y\prime + \mu = b_0 + b_1 X_1 + \cdots + b_k X_k\,. \tag{6}$$

As can be seen from the formula (1), the dependent variable y is made up of two parts. The first part $y\prime$ is the estimated value of the dependent variable y, which is the part determined by the independent variable; μ is the residual, which is the part not determined by the independent variable. The μ is very important to determine whether the current model is established and whether there are other variables that need to be introduced into the model and a series of problems. In formula (1), b_0 is a constant term, which represents the intercept of the equation; b_i is the partial regression coefficient, which represents the variation of independent variable X_i with changing 1 unit when other independent variables are fixed. Multiple linear regression not only need to test the of regression coefficient, estimate the confidence interval of regression coefficient, and discuss about prediction and hypothesis testing, etc, but also need to consider the relationship among various independent variables, such as whether there is the collinearity problem among them.

3.2. Implementation process of multiple linear regression based on SPSS

The SPSS implementation steps after entering the data are as follow: click in proper order Analyze→Regression→Linear, the main dialog box of Linear Regression (linear regression analysis) appears. The dependent variables are selected into Dependent (dependent variable), independent variables are selected into the Independ (independent variables), selecting the Part and partial correlations, Collinearity diagnostics (collinearity diagnostics) Estimates, Model fit, and then click OK. The imitative effect is determined by the F value in analysis of variance table and R^2 value in the model overview table, and the problem whether there is collinearity is determined by the regression coefficient and correlation and collinearity statistics of the significance testing table. If there is the problem of collinearity, the dependent variables need to be filtered. In order to overcome the collinearity problem, simplify the model and increase the accuracy of prediction, this paper selects stepwise regression method, the SPSS implementation steps are as follows: on the basis of the above operations, select Stepwise (step by step) in the Method box, and then click OK.

R^2 determination coefficient is the model overview table of output results, which reflects the regression effect, the closer to 1 it is, the better the effect is; correction determination coefficient $R^2_{adj} = 1 - (1-r)\,(n-1)/(n-k)$ (n is the sample number, k is the number of independent variables), which reflects the effect of R^2 excluding the degree of freedom. In the analysis of variance table, F is used to test the regression effect. $F =$ explained variables and unexplained variable, the greater the value is, the better the regression effect is. According to the significance of the t test of the regression coefficient, the corresponding variable is determined whether can be used as an explanatory variable into the regression equation. The regression coefficient and the variable b in the significant testing table are the coefficients of the regression equation, and the b value of the constant is the intercept of the regression equation. Correlation and collinearity statistics are used for the detection of multiple collinearity problems.

4. Degree of safety of stope face SPSS multivariate regression analysis and results testing

4.1. Specific implementation process of SPSS multiple regression

Logging data, select the Analyze→Regression→Linear on the SPSS menu bar, the main dialog box of Linear Regression appears, y will be selected into the Dependent, X_1 to X_{13} will be selected into the Independ, select Estimates, Model fit in the Statistics option, and then click OK. Part output results are shown in Table 1 to 3.

From Table 1, it can be found that the equation is meaningful from the F test results of the model. The R^2 is the proportion of the total variance of the dependent variable y can be explained by the regression equation. From Table 2, $R^2 = 0.998$ can be obtained, indicating that the model explains the variation of the safety degree of 99.8%, the regression effect is very good. However, from table 3, it can be seen that a lot of partial regression coefficients are not significant, indicating that their corresponding independent variables may have no significant impact on the safety degree, so the introduction of these variables in the model has no practical significance. The minimum value of variance inflation factor (VIF) is 5.426 (usually if VIF is more than 2, the collinearity problem may exist); from tolerance, it can be seen that 80% $\sim$ 99% of degree of change can be explained by other variables for the given variables, so there are many multi-collinearity problems in the model.

Table 1. Degree of safety and relevant parameters of stope face

NO.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	y
1	1 92	408	2 0	10	2 0	155	4 42	0 96	2 02	1. 50	20	5. 03	1825	3 34
2	2 15	411	2 0	8	2 0	140	4 16	0 95	2 10	1. 21	22	4. 87	1527	2 97
3	2 14	420	1. 8	11	1. 8	175	4 13	0 95	2 64	1. 62	19	4. 75	1751	3 56
4	2 58	432	2 3	10	2 3	145	4 67	0 95	2 40	1. 48	17	4. 91	2078	3 62
5	2 40	456	2 2	15	2 2	160	4 51	0 94	2 55	1. 75	20	4. 63	2104	4 17
6	3 22	516	2 8	13	2 8	180	3 45	0 93	2 21	1. 72	12	4. 78	2242	4 60
7	2 80	527	2 5	17	2 5	180	3 28	0 94	2 81	1. 81	11	4. 51	1979	4 92
8	3 35	531	2 9	9	2 9	165	3 68	0 93	1. 88	1. 42	13	4. 82	2288	4 78
9	3 61	550	2 9	12	2 9	155	4 02	0 92	2 12	1. 60	14	4. 83	2325	5 23
10	3 68	563	3. 0	11	3. 0	175	3 53	0 94	3. 11	1. 46	12	4. 53	2410	5 56
11	4 21	590	5. 9	8	5. 9	170	2 85	0 80	3. 40	1. 50	18	4. 77	3139	7 24
12	4 03	604	6 2	9	6 2	180	2 64	0 81	3. 15	1. 80	16	4. 70	3354	7 80
13	4 34	607	6 1	9	6 1	165	2 77	0 78	3. 02	1. 74	17	4. 62	3087	7 68
14	4 80	634	6 5	12	6 5	175	2 92	0 77	2 98	1. 92	15	4. 55	3620	8 51
15	4 67	640	6 3	11	6 3	175	2 75	0 80	2 56	1. 75	15	4. 60	3412	7 95
16	2 43	450	2 2	12	2 2	160	4 32	0 95	2 00	1. 70	16	4. 84	1996	4 06
17	3 16	544	2 7	11	2 7	165	3 81	0 93	2 30	1. 80	13	4. 90	2207	4 92
18	4 62	629	6 4	13	6 4	170	2 80	0 80	3. 35	1. 61	19	4. 63	3456	8 04

Table 2. Analysis of variance

Index	Sum of squares	Degree of freedom	Mean square error	F	Sig
Regression	43.276	11	3.932	104432	0.010
Residual	0.072	2	0.037		
Total	43.352	12			

Table 3. Model overview

r	R2	Correction determination coefficient (R^2_{adj})	Standard margin of error
0.999	0.998	0.989	0.1941

It can be seen that stepwise regression method finally selects mining strength $X_{13}\,(t/d)$, advancing speed $(t/d)\,(m/d)$ and inter-layer lithology X_{12} as predictor variables instead of other variables to establish the model due to the existence of multi-collinearity among independent variables, the regression coefficients are significant, that is the selected variables are have a significant impact on the safety degree. The b value is the partial correlation coefficient and the intercept, so the regression equation can be established as follow:

$$y = 0.002161X_{13} - 0.566X_7 - 1.206X_{12} + 7.852\,. \tag{7}$$

4.2. Method test

We compare this method with regression analysis method in literature 11 , literature 12, literature 13, literature 14, literature 15 and literature 16. The regression equation (3) is used to calculate the safety degree and relative error of No. 15, 16, 17 and 18 stope face of the mine, which are shown in Table 4.

Table 4. Contrast between actual value and predicted value

No. of working face	Index of safety degree		Relative error/%
	Actual value	Predicted value	
15	7.94	7.8632	1.236
16	4.02	4.2356	4.632
17	4.91	5.2641	7.25
18	8.03	7.6359	5.21

From Table 4, it can be known that the predicted maximum relative error of the model is 7.25%, the minimum error is only 1.236%, and the average error is 4.632%. The average error is 4.196% obtained by the prediction model of neural network, the predicted average error is 4.93% obtained by principal component regression analysis model, the predicted average error is 4.675% obtained by grey relational analysis model, but the accuracy of prediction interval given by the fuzzy comprehensive evaluation method is lower than above algorithms. From the prediction accuracy, the accuracy of this method used by this paper is just lower than that of neural network model, so this model has high accuracy.

Compared with the existing prediction methods, the establishment process of this method is simple, and greatly reduces the computation time, has intuitive result and high accuracy, is convenient for popularization and practical application, can easily finds the factors on the safety degree of stope face having the significant impact. In order to better carry out the safety governance and provide the basis for exploitation, this method can also be used to predict the source of mined bed, adjacent bed and goaf district. This method is established on the basis of rigorous statistical theory, which has strong dependency on the sample, higher requirements on the sample, the more accurate predicting results can be obtained when the training samples are enough and have typicality and representativeness.

4.3. Direct effect analysis of safety regulations on technological innovation of enterprises

According to the above theoretical analysis and model building, in order to avoid multi-collinearity among variables, the empirical analysis carries out the regression analysis on direct effect model by introducing variables one by one, and the valuable conclusions are drawn, From literature 11 , literature 12, literature 13, literature 14, literature 15 and literature 16, comparison of the parameters with these methods, the specific results are as shown in Table 5.

Table 5. Direct effect of safety regulations on technological innovation of enterprises

variable	Model1	Model2	Model3	Model4	Model5	Model6
$R\&D_{-1}$	1.1133***	1.1101***	1.1055***	1.0969***	1.0320***	1.0130***
	(2937.1500)	(4047.8200)	(3926.5900)	(2495.9500)	(1162.0100)	(129.5700)
ERS	−1.6333***	−16.7186***	−16.4829***	−18.7070***	−6.1636***	−9.5275**
	(−6.4900)	(−27.8800)	(−20.0700)	(−16.2300)	(−2.9500)	(−2.4900)
ERS^2		22.3928***	22.3277***	25.6475***	9.9013***	13.2170**
		(32.1300)	(23.2000)	(14.3000)	(3.4700)	(2.4300)
SIZE			0.1072**	0.1573***	0.1249***	0.0824***
			(3.2000)	(4.4400)	(10.7200)	(6.2600)
FDI				0.9295***	0.9236***	0.5566***
				(20.8300)	(11.0000)	(4.5300)
PROFIT					3.6708***	3.3461***
					(90.27)	(37.3300)
WAGE						1.7568***
						(4.9700)
C	1.5935***	2.4948***	2.2403***	−6.8161***	−8.4253***	−21.7488***
	(11.0000)	(12.9400)	(16.0900)	(−13.6600)	(−13.5500)	(−6.9100)
Sargan	23.7095	22.2172	22.8548	25.0937	23.2955	24.6861
	(0.3073)	(0.3871)	(0.3518)	(0.2431)	(0.3284)	(0.2610)
AR(1)	−2.5760	−2.5423	−2.5263	−2.5130	−2.5536	−2.5232
	(0.0100)	(0.0110)	(0.0115)	(0.0120)	(0.0107)	(0.0116)
AR(2)	−1.6338	−1.5459	−1.5092	−1.3700	−0.2128	−0.2411
	(0.1023)	(0.1221)	(0.1312)	(0.1707)	(0.8315)	(0.8095)

In Table 5, the excessive recognition constraint of zero hypothesis tested by Sargan is valid. This test not only requires that the first order difference of residuals is negatively correlated, but also requires the correlation of more than second order is non-existed. After regressing formula (1), P value is at 0.24 to 0.38 tested by Sargan, to accept the original hypothesis, namely the selection of instrumental variables introduced into Table 1 model are reasonable and effective; the residuals obtained from difference equation comply with AR (1) and AR (2) process, the P value of AR (1) is 0.01, which indicate to refuse non-existing original hypothesis of first-order autocorrelation, there are first-order autocorrelation among variables; the test results of AR (2) are greater than 0.1, which indicates that there are only first-order negative correlation in the residual series of sample, there is no serial correlation more than second-order. The results of Sargan test, AR (1) and AR (2) in Table 5 show that the selection of instrumental variables in the model is reasonable, and the identification of the model is effective.

5. Conclusion

1) The influencing factors of safety degree have 14, there is multi-collinearity problem among independent variables by collinearity diagnosis, and finally selecting 3 variables of mining strength, advancing speed, inter-layer lithology to establish regression model through regression analysis. The model building process of this method is simple, has intuitive results and high precision, and is convenient for popularization and practical application

2) This method has a higher requirement on the samples, and the more accurate predicting results can be obtained when the training samples are enough and have typicality and representativeness.

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