Evaluation of Coupling and Coordinated Development of EES Composite Systems in North China

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June 26, 2022

Abstract

The coupling relationship between Ecology, Economy and Society has been paid more and more attention in recent years. This project sets the indices qualitatively and uses entropy weight to calculate the weights of indices quantitatively. Using such indices and the corresponding indices, this project calculates and analyzes subsystem coherence in six provinces. Then utilizing methods like linear regression, this project analyzes how different indices affect coherence. Finally, according to the analysis, this project provides advice for policymakers.

Contents

1 Introduction

1.1 Background

The environment that human beings depend on is a complex system consisting of economy, society, and ecology subsystems. Recent years have witnessed the considerable pursuit of continuous, coordinated development due to the increasing conflict between economic growth and the eco-environment. Thus, a systematic method to determine how the development of economy, society, and ecology subsystems are coordinated is vital to give a quantitative measure, which can be used to evaluate the current situation and guide policymakers. Especially, the decoherence between subsystems indicates the potential conflicts between human beings and wildlife, and a thorough investigation of those subsystems can obtain the underlying factors of threats to wildlife habitats.

1.2 Literature review

Li Chenyun et al introduced the achievements made by China in the field of endangered wildlife protection, analyzed the existing problems and came up with suggestions with the expectation to formulate effective and targeted methods and polices to protect endangered wildlife.

The research carried out by Ma Jianzhang et al pointed out that due to the rapid increase of population and economics enhanced the requirement and stress of environment, the habitat fragmentation has been getting more and more seriously. However, the wildlife protection in China commenced from the new China established, and consummated gradually with the development of society and economics, resulting in many achievements in wildlife protection.

1.3 Structure and Method of the Article

For empirical research, we consider the data in the three subsystems between 2000-2020 in Beijing as an example. For those steps needing data from various regions, data from six provinces, including Beijing, Tianjin, Hebei, Shandong, Shanxi, and Henan, is considered.

The steps of our research are: First, choose variables in subsystems, and Then use the entropy weight method as an objective method to determine the information carried by those variables, in order to determine the weight. Second, we use the Coupling Function to determine the coherence score in the subsystems so as to figure out how those subsystems are coordinated during the given period. Then using the coherence score as a response variable, we carry out linear regression, Lasso, xgboost methods to fit the coherence score, and the performances of those methods are compared. Besides, we compare the coherence scores in different regions in order to find how the coordinated development is differentiated between provinces. Additionally, a simple prediction of coherence score in the Beijing area is implemented by the time series model.

2 Data description and Exploratory Data Analysis

2.1 Description of Data

We include 3 categories of total 24 variables to carry out our research, including 11 variables in economy subsystem, 10 variables in society subsystem and 3 variables in ecology subsystems. The data is collected annually typically from 2000 to 2020 in the area of Beijing, although some of the statistics stopped early than 2020 or began later than 2000, resulting in some missing values.

2.2 Tackling the missing values

We need complete data in order to build an evaluation system, as well as carry out regression analysis. First, we detect the position of missing values in the data set, which is shown in in figure 1.

As is shown in the figure, about 1/3 of the variables have missing values, despite few missing values inside the series, most missing values stand at the begin or the end of the time series. Also, most variables have significant trend across the time. Thus, it is a bad idea to use average value to replace the missing values. To better retain the trend while largely preserve the information, we use the IterativeImputer in python's sklearn package to fill the missing date using the iterative method.

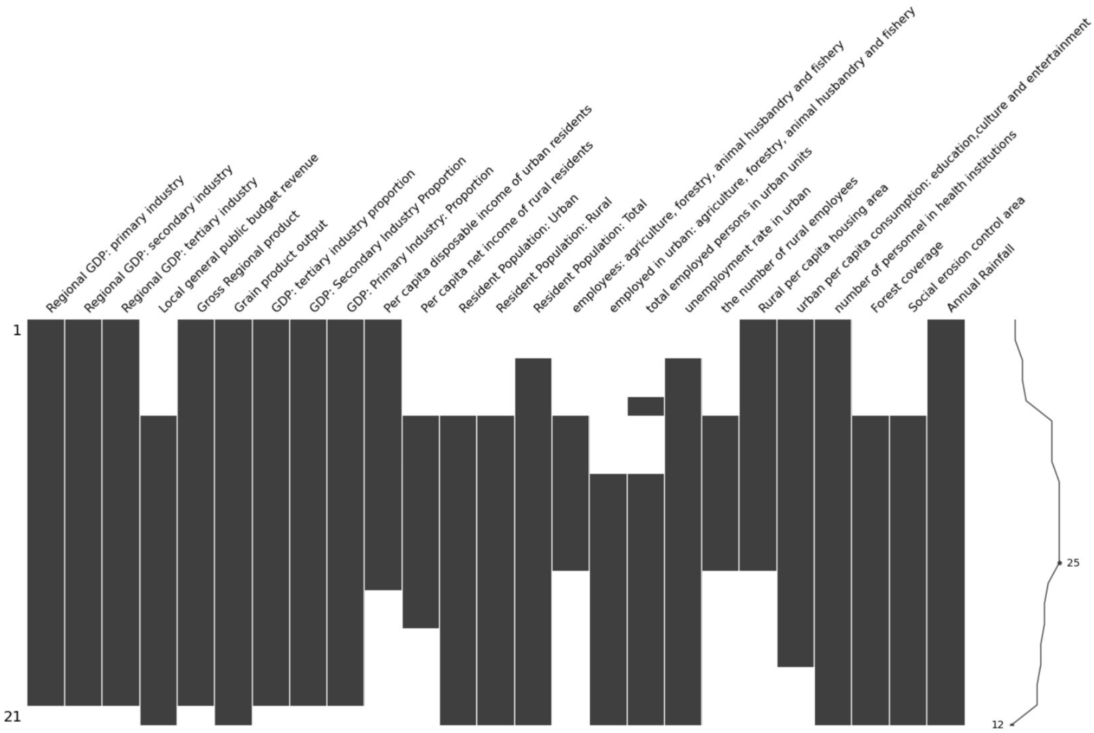

Figure 1: Missing value detection

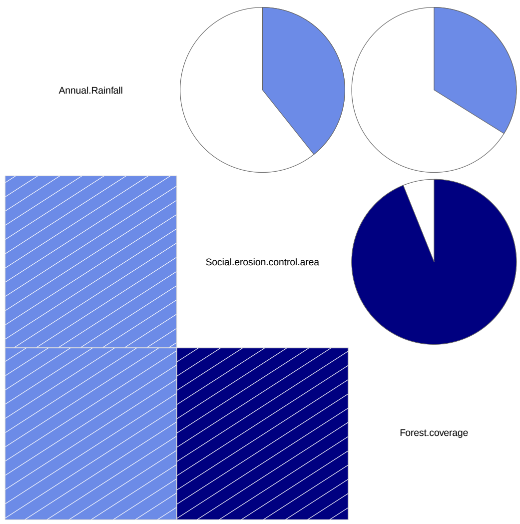

Figure 2: Ecology Correlation

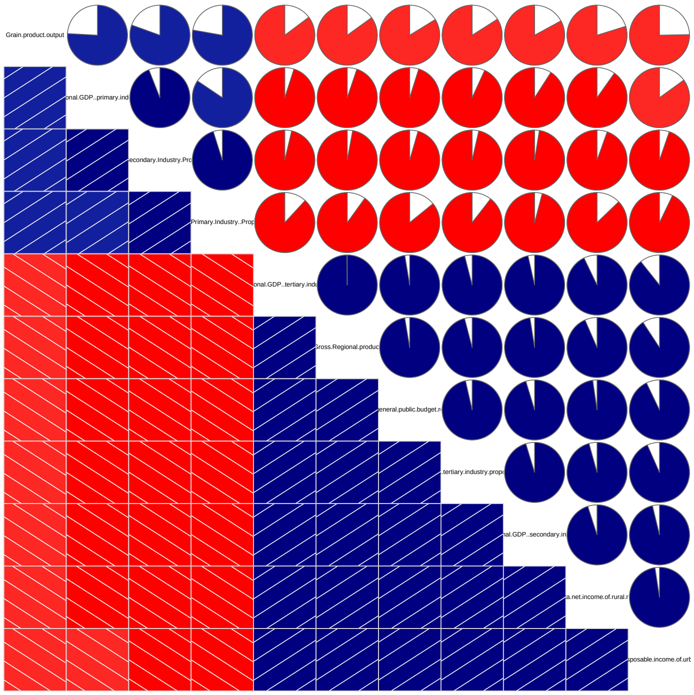

Figure 3: Economy Correlation

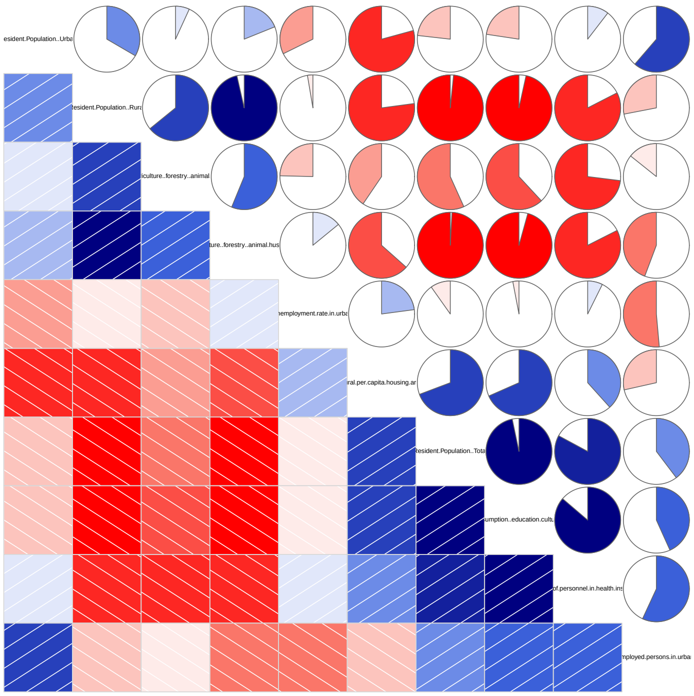

Figure 4: Society Correlation

2.3 Correlation between variables

From the plots above, we can see that multicolinearity is significant. On the one hand, this phenomenon is due to the fact that part of the data is linearly correlated. For instance, the proportions of primary, secondary and tertiary industry, whose sum is no doubt 1. Hence, we should consider deleting some of this kind of variables. On the other hand, some of the data has implicit relationship. For example, the employed population and the regional GDP should be strongly connected intuitively. This kind of relationship must be tackled properly.

2.4 Distribution of each variables

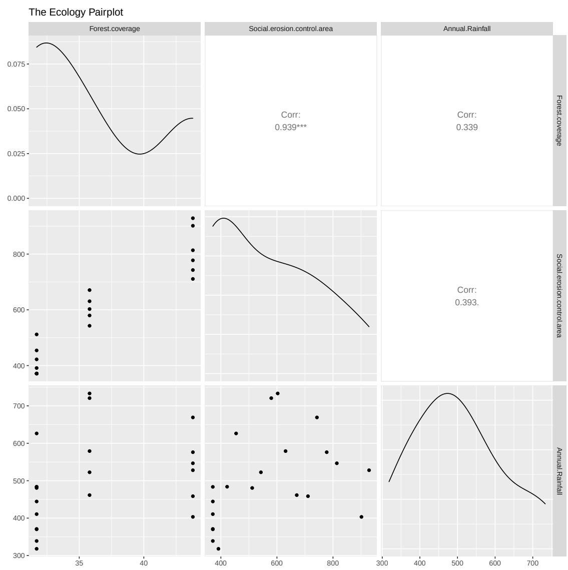

Figure 5: Ecology Pairplot

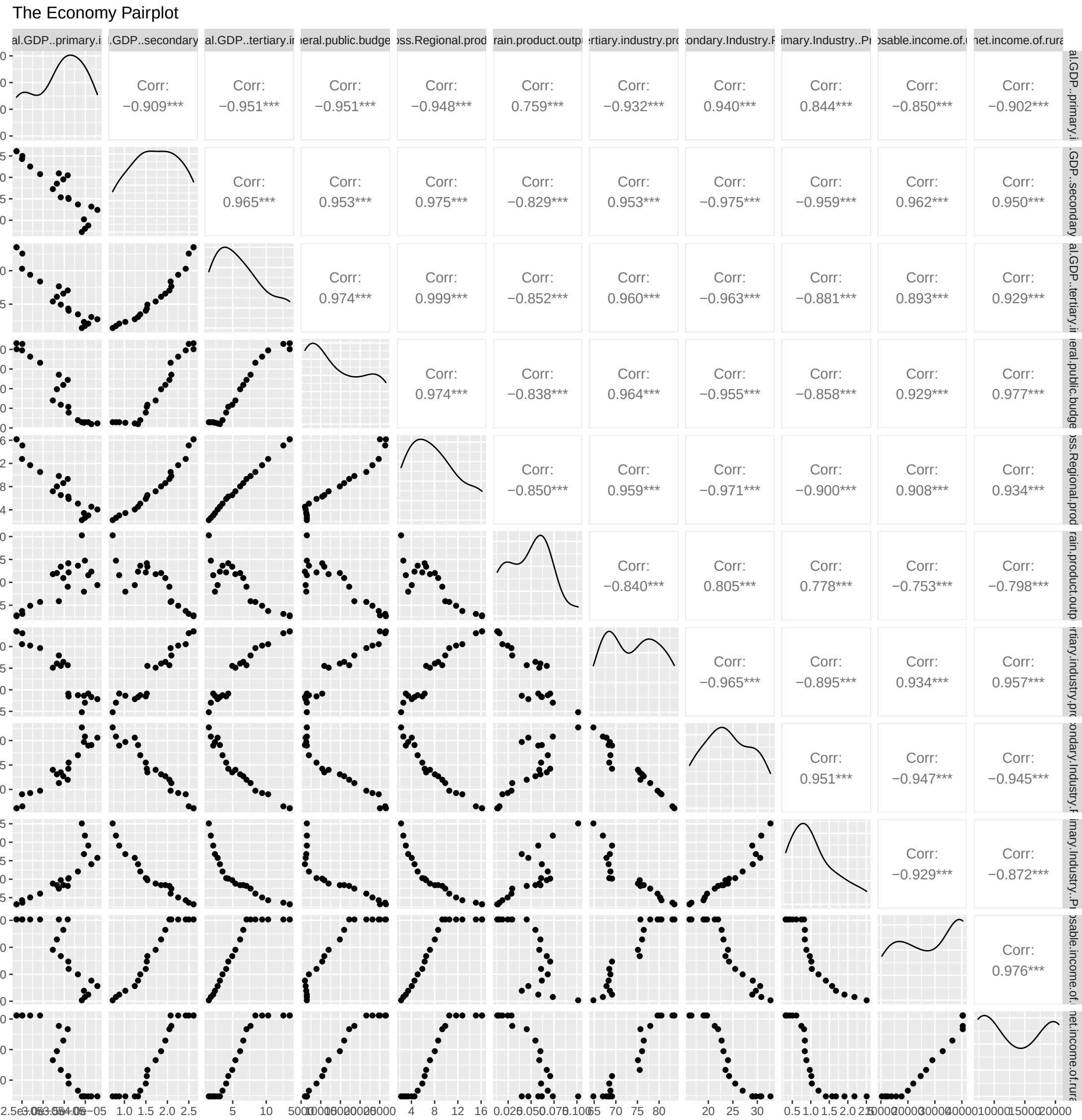

Figure 6: Economy Pairplot

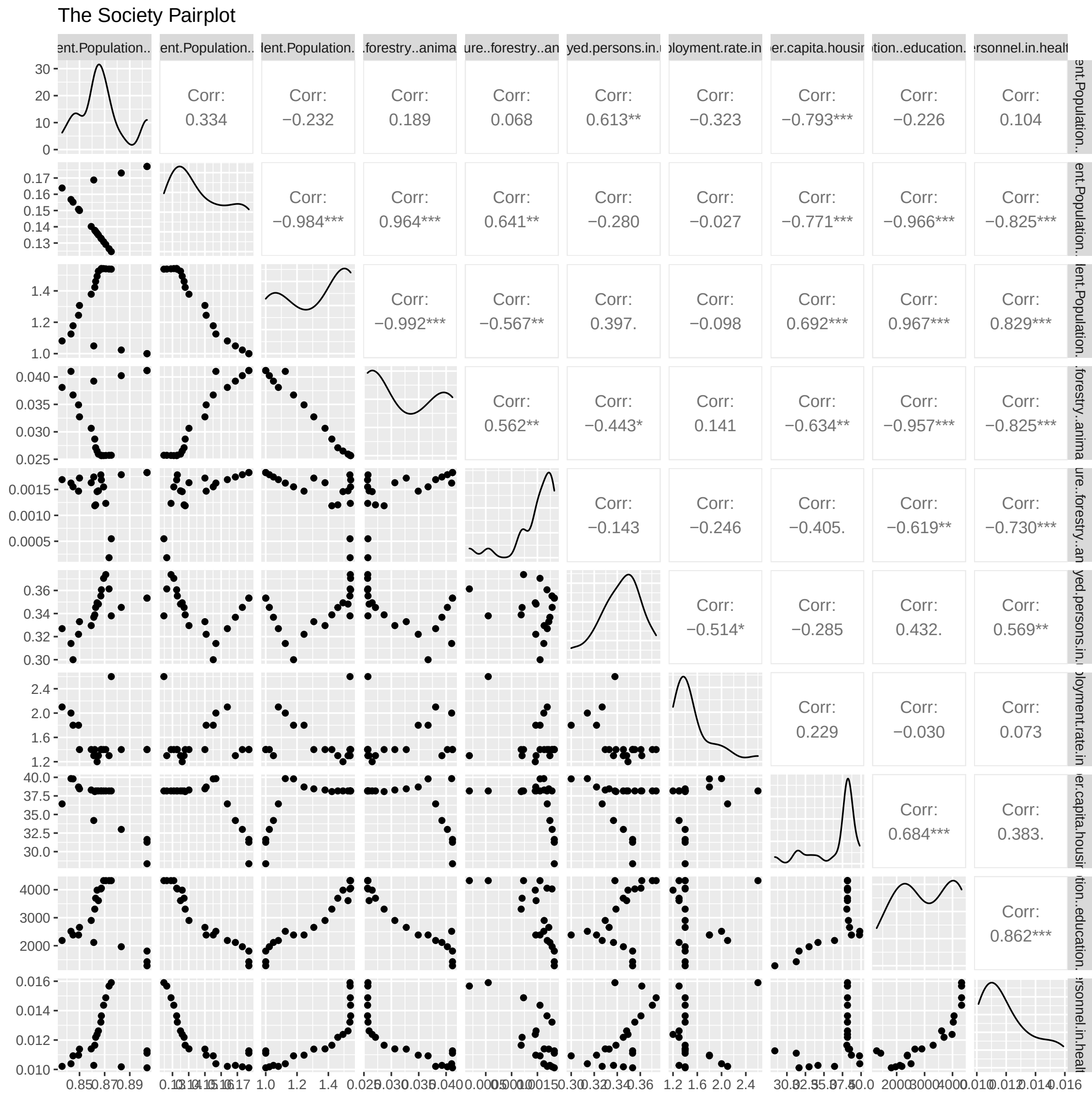

Figure 7: Society Pairplot

As is shown in the figure, most of the data is right-skewed while a few of them is left skewed or multi-modal. Hence, we should consider transformations later to rectify the data, constructing an appropriate model.

3 Quality Evaluation System of Wildlife Habitat: Beijing as example

3.1 Evaluation indicators in Subsystems

To evaluate the quality of habitats, we should first construct the evaluation system of each subsystems, and then use the evaluation of subsystems to build a complete evaluation system of wildlife habitats. In other words, the system should be built in the following two steps:

$$\phi_i = \sum \omega_{ij} \varphi_{ij} \tag{1}$$

$$\Phi = \sum \Omega_i \phi_i \tag{2}$$

Φ refers to the total score quality habitat, ϕ_i refers to quality of a subsystem, φ_{ij} refers to the score of each indicators. Ω_i, ω_{ij} refer to the weight of a subsystem and each indicator.

Positive/negative indicators used refer to [?] The subsystems, indicators in the subsystems, as well as positive/negative indicators is shown in table 1:

	Predictor	Positive/Ne
Economy Subsystem	**Regional GDP: primary industry**	+
	Regional GDP: secondary industry	+
	Regional GDP: tertiary industry	+
	Local general public budget revenue	+
	Gross Regional product	+
	Grain product output	+
	GDP: tertiary industry proportion	+
	GDP: Secondary Industry Proportion	+
	GDP: Primary Industry: Proportion	+
	Per capita disposable income of urban residents	+
	Per capita net income of rural residents	+
Society Subsystem	**Resident Population: Urban**	+
	Resident Population: Rural	-
	Resident Population: Total	+
	employees: agriculture, forestry, animal husbandry and fishery	+
	employed in urban: agriculture, forestry, animal husbandry and fishery	+
	total employed persons in urban units	+
	the number of registered unemployed in urban areas	-
	Rural per capita housing area	+
	urban per capita consumption: education,culture and entertainment	+
	number of personnel in health institutions	+
Ecology Subsystem	**Forest coverage**	+
	Soil erosion control area	+
	annual rainFall	+

Table 1: Preditors and positive/negative

3.2 Weight of each indicator

Many methods are used in recent research to determine the weight of a certain indicator. To prevent subjective judgement, we choose the entropy weight method to determine the weight of each indicator. First, we scale the variables to make them comparable, the method is:

For positive indicators:

$$Y_{ij} = \frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)} \tag{3}$$

For negative indicators:

$$Y_{ij} = \frac{\max(X_i) - X_{ij}}{\max(X_i) - \min(X_i)} \tag{4}$$

Then we calculate the percentage of each year during the 21 years for each indicator.

$$p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}, i = 1, \cdots, n, j = 1, \cdots, m \tag{5}$$

Using the information theory, we calculate the information entropy as

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{6}$$

Finally, we calculate the information redundancy in order to calculate the weight,

$$D_j = 1 - E_j \tag{7}$$

$$w_j = \frac{D_j}{\sum_{j=1}^{m} D_j} \tag{8}$$

Using the above-mentioned method, the weight of each subsystems is shown in table.

	Economy
Regional GDP: primary industry	0.11074880225154300
Regional GDP: secondary industry	0.11663785767780600
Regional GDP: tertiary industry	0.08579387186237840
Local general public budget revenue	0.04794307959814680
Gross Regional product	0.093953170584893
Grain product output	0.10126957295268000
GDP: tertiary industry proportion	0.11220775281229400
GDP: Secondary Industry Proportion	0.10469002514141200
GDP: Primary Industry: Proportion	0.07744426908675940
Per capita disposable income of urban residents	0.10625056084972500
Per capita net income of rural residents	0.04306103718236320

	Society
Resident Population: Urban	0.10831134273668200
Resident Population: Rural	0.09306852658473350
Resident Population: Total	0.08116605621358230
employees: agriculture, forestry, animal husbandry and fishery	0.0349049395813636
employed in urban: agriculture, forestry, animal husbandry and fishery	0.13000357923491100
total employed persons in urban units	0.12406353363827800
unemployment rate in urban	0.1309019304982310
Rural per capita housing area	0.12666639522874100
urban per capita consumption: education,culture and entertainment	0.10558314403652800
number of personnel in health institutions	0.06533055224695040

	Ecology
Forest coverage	0.2733040664832910
Social erosion control area	0.32728538516981000
Annual Rainfall	0.39941054834690000

3.3 Coupling Function

Using the entropy method, we can calculate the weights of each entry in each subsystem. Then, we can further calculate the scores of each subsystem U_{it}, where i stands for the ith subsystem and t stands for year t. The definition of U_{it} is as followed:

$$U_{it} = \Sigma_j^{i_k} w_{ij} u_{ij} \tag{9}$$

The scores of subsystems are as followed:

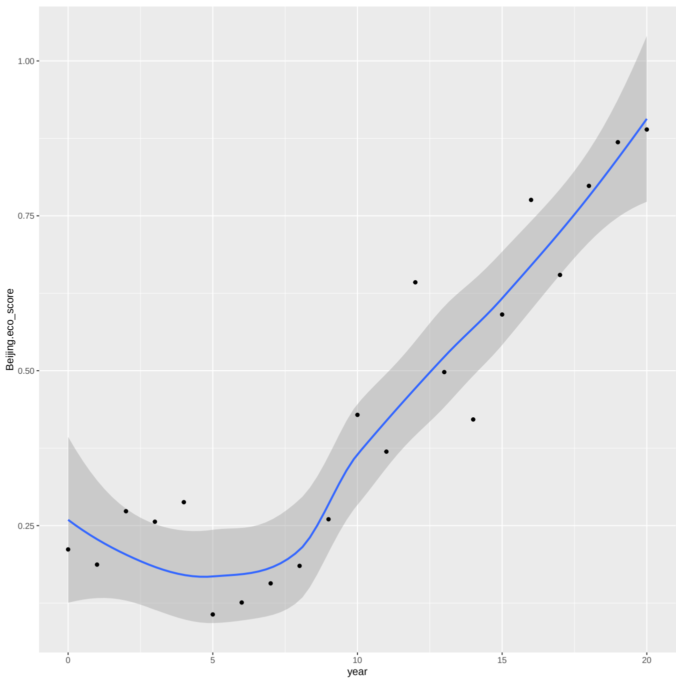

Figure 8: Beijing Ecology Score

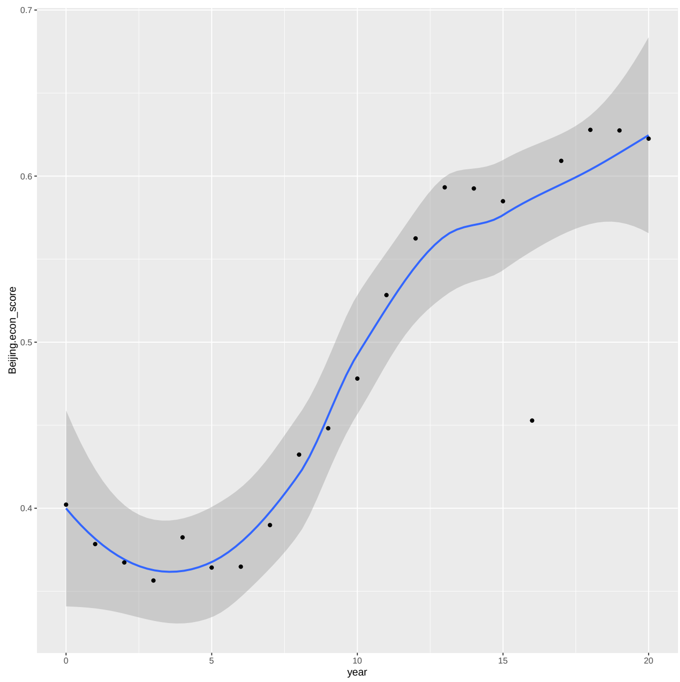

Figure 9: Beijing Economy Score

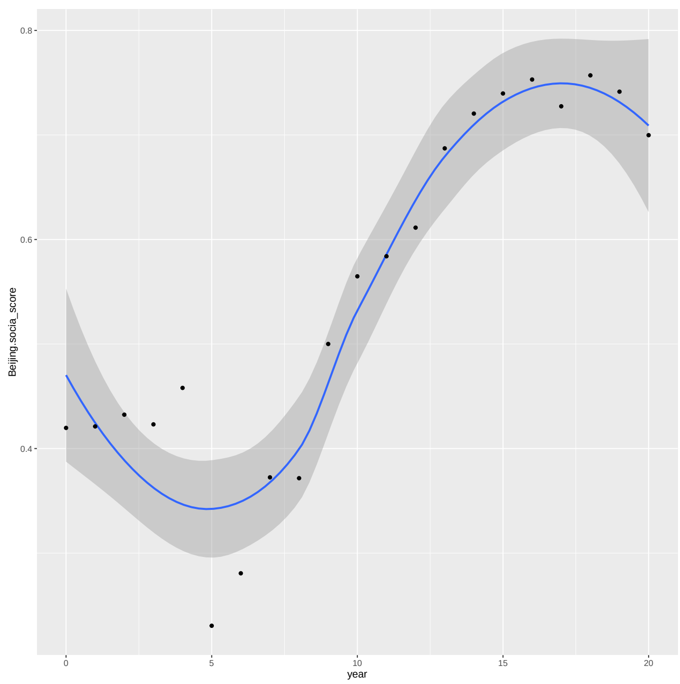

Figure 10: Beijing Society Score

Using the score of each Subsystems, we can also derive the weight of each subsystems, which is shown in figure:

	Subsystem
Beijing.eco_score	0.320144
Beijing.econ_score	0.333288
Beijing.socia_score	0.346568

According to the literature, we can define the coupling function:

$$C = (\frac{(U_1 \times U_2 \times U_3)}{(U_1 + U_2 + U_3)^3})^{\frac{1}{3}} \times 3 \tag{10}$$

We can further use $1-C$ to represent decoherence. However, since the level of decoherence is too low, we should enlarge it by a parameter 10000. The result is as followed:

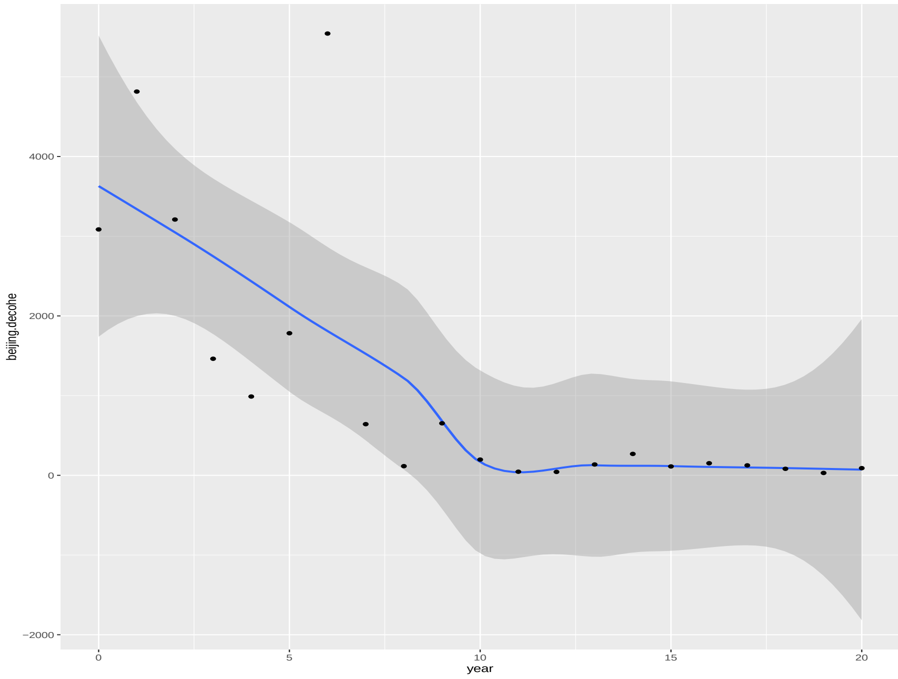

Figure 11: Decoherence

What's more, with this simple coherence, we can only see the coherence between the subsystems. However, we can't clearly figure out whether, for example, high coherence occurs in high level or low level of development. Hence, we should also take the total score of subsystems into consideration, defining the following Adjusted-Coherence:

$$D = \sqrt{C \times T} \tag{11}$$

where T represents the total score of the subsystems. The result is as followed:

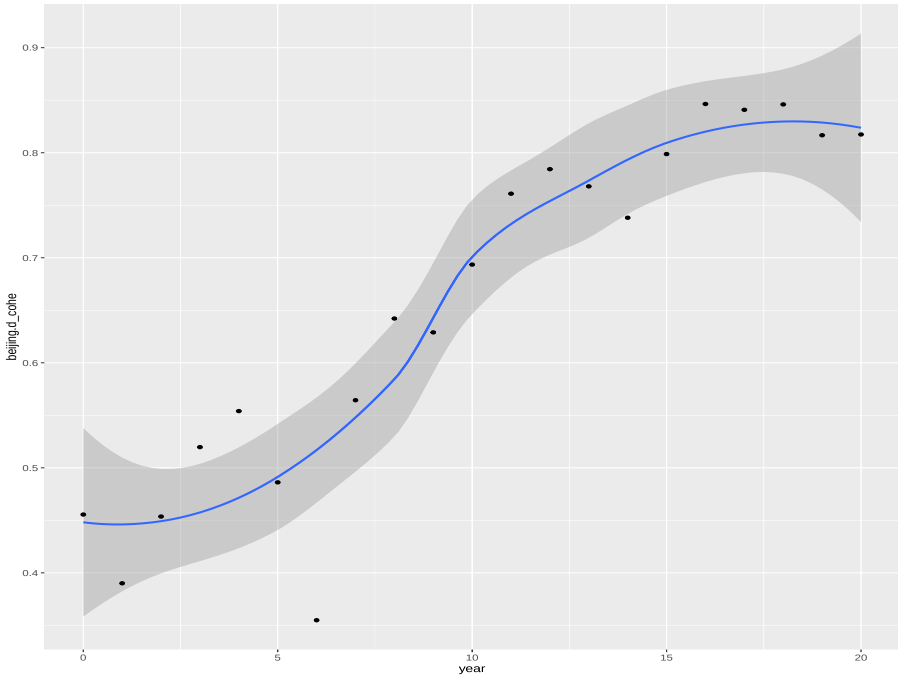

Figure 12: Coherence

4 Linear Regression

4.1 Pre-Dimension Reduction

First of all, we should notice that there are only 21 years of data while there are 28 explanatory variables. Also, from the exploratory data analysis, we can find multilinearity between variables. To make linear regression feasible, we first consider pre-Dimension Reduction using multivariate statistical methods.

4.1.1 Principle Value Decomposition

Since the ecology system have moderate number of variables, we only apply dimensional reduction method on economy and social systems respectively. The variance explained by each component is shown in the figure (economy) and figure (society):

We can see a sharp decline in the variance explained at components number of 3(economy subsystems) and 4(social subsystems), so we choose this number of components as the target dimension.

However, the eigenvectors of the results shows poor interpretability. Therefore, we try factor analysis for better interpretability.

4.1.2 Factor Analysis

We use the Maximum Likelihood Estimator to estimate the parameters and ”promax” method to rotate the factors, the factor loadings is shown in figure (economy subsystems) and figure(social subsystems).

We can see better interpretability here. Hypothesis test shows 3(economy) and 4(society) factors is enough. So we estimate the loadings in figure , which are used in the following

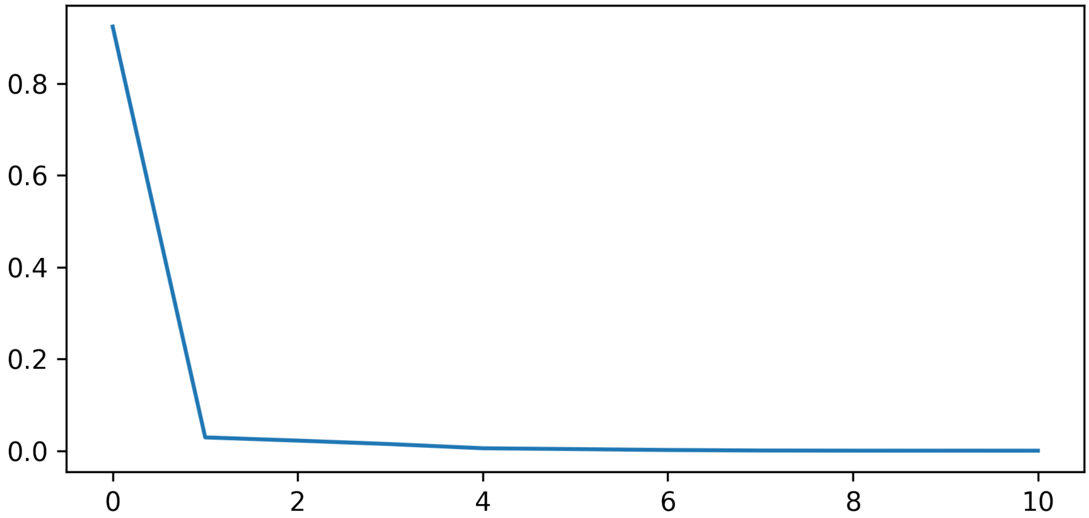

Figure 13: Variance explained by each components: in Economy Subsystems

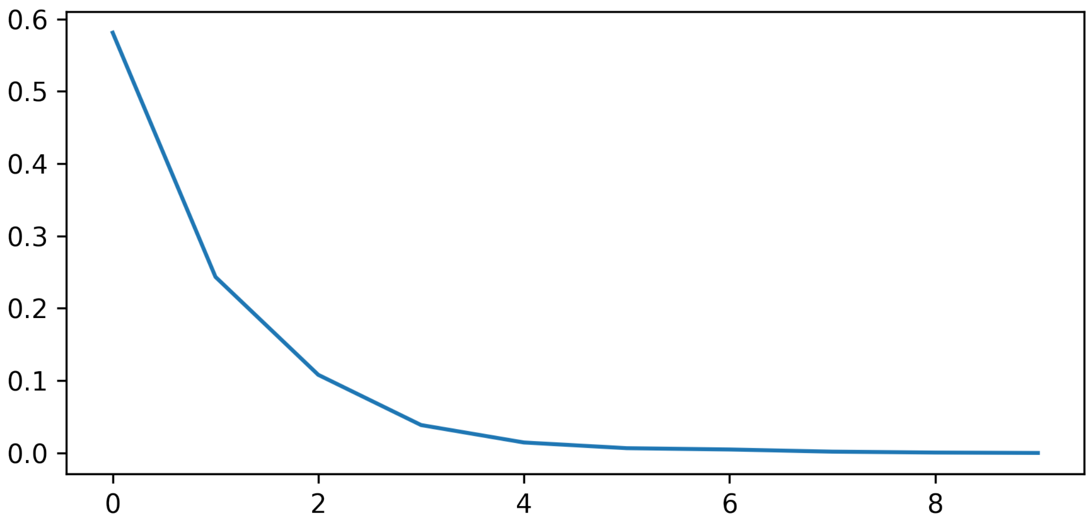

Figure 14: Variance explained by each components: in Society Subsystems

	0	1	2
Regional GDP: primary industry	-0.777619	-0.145539	0.057145
Regional GDP: secondary industry	0.410282	0.220086	-0.431502
Regional GDP: tertiary industry	0.881826	0.026517	-0.115254
Local general public budget revenue	0.716620	0.384401	0.069942
Gross Regional product	0.804640	0.046561	-0.183336
Grain product output	-0.668468	-0.031823	0.176780
GDP: tertiary industry proportion	0.593422	0.294823	-0.148017
GDP: Secondary Industry Proportion	-0.475362	-0.208139	0.371534
GDP: Primary Industry: Proportion	-0.106605	-0.066991	0.855085
Per capita disposable income of urban residents	-0.010344	0.695273	-0.365481
Per capita net income of rural residents	0.332728	0.690787	-0.017702

Figure 15: Factor loadings: in Economy Subsystems

	0	1	2	3
Resident Population: Urban	-0.165410	0.903335	-0.005473	-0.070537
Resident Population: Rural	-0.939948	0.186631	-0.006598	0.055244
Resident Population: Total	0.999065	-0.090834	-0.045519	0.037897
employees: agriculture, forestry, animal husbandry and fishery	-0.979677	0.045593	0.078191	-0.022772
employed in urban: agriculture, forestry, animal husbandry and fishery	-0.125602	-0.002850	0.066854	0.948489
total employed persons in urban units	0.555454	0.741544	-0.131681	0.135303
unemployment rate in urban	0.042730	-0.071983	0.996884	0.058595
Rural per capita housing area	0.600746	-0.751114	-0.019916	-0.014724
urban per capita consumption: education,culture and entertainment	0.986492	-0.039275	0.027880	0.002372
number of personnel in health institutions	0.833831	0.346899	0.214371	-0.171159

Figure 16: Factor loadings: in Society Subsystems

regression analysis together with ecology indicators.

4.2 Multiple Linear Regression

Using the result of factor analysis, we can construct a preliminary model.

Here is the diagnostic plot:

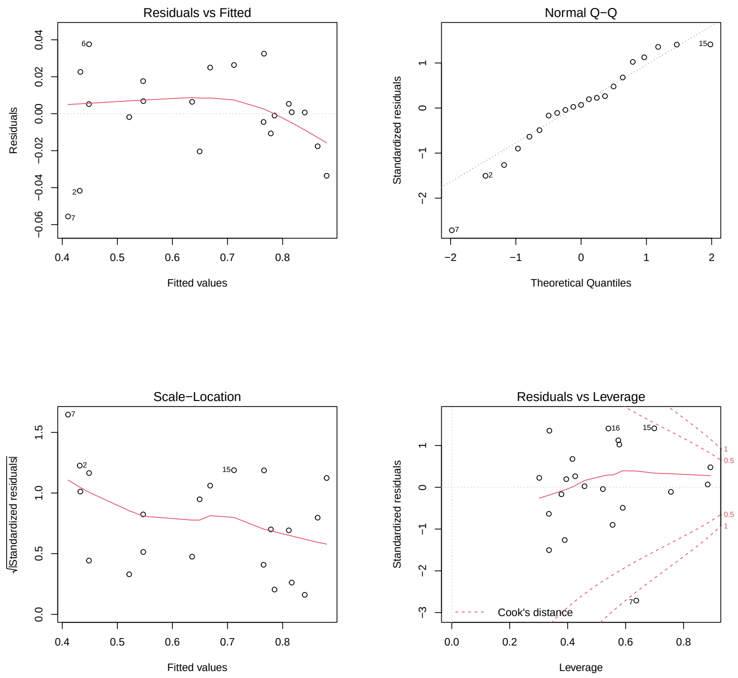

Figure 17: Diagnostics

```
Call:
lm(formula = response ~ ., data = beijing.pca_data)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.055591 -0.010676  0.000799  0.017627  0.037567 

Coefficients:
                             Estimate Std. Error t value Pr(>|t|)    
(Intercept)                  0.655258   0.007422  88.287  8.5e-16 ***
economy_1                    0.014939   0.032528   0.459  0.65587    
economy_2                    0.018015   0.044558   0.404  0.69450    
economy_3                   -0.034784   0.029742  -1.170  0.26931    
social_1                    -0.050889   0.080325  -0.634  0.54060    
social_2                     0.002392   0.020422   0.117  0.90906    
social_3                    -0.021832   0.013411  -1.628  0.13461    
social_4                     0.018687   0.016126   1.159  0.27347    
Forest.coverage             -0.011032   0.034072  -0.324  0.75277    
Social.erosion.control.area  0.133601   0.077696   1.720  0.11626    
Annual.Rainfall              0.054770   0.010381   5.276  0.00036 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.03401 on 10 degrees of freedom
Multiple R-squared:  0.9784,	Adjusted R-squared:  0.9569 
F-statistic: 45.38 on 10 and 10 DF,  p-value: 5.459e-07
```

Figure 18: Summary

It is obvious that there might be non-linear relationship and some high influential points. Also, it seems that the variance might not be constant, suggesting some kinds of transformation or weighted regression. From the summary table, there is no doubt that the model is significant since the p-value is far less than 0.05. Also, the fitting ability of the model is marvelous as the R^2 is up to 0.9784 and adjusted R^2 is up to 0.9569. Nonetheless, the partial regression effects of variables are rather poor. Only Annual.Rainfall shows crucial explanatory ability, which indicates the necessity of variable selection.

Furthermore, we can calculate the variance inflation factor to determine the multicolinearity.

```
> vif(reg.general)
         economy_1             economy_2             economy_3              social_1              social_2              social_3 
         22.252425             38.958359             18.394074            116.987107              7.559807              3.255954 
          social_4       Forest.coverage Social.erosion.control.area       Annual.Rainfall 
          4.706638             21.074528            109.587973              1.956481 
```

Figure 19: Variance Inflation Factor

From the VIF, it's obvious that multicolinearity is conspicuous since most of the VIFs of variables are larger than 10, suggesting that variable selection is necessary.

Also, we shall use mallow's C_p and stepwise to determine which variable we should keep.

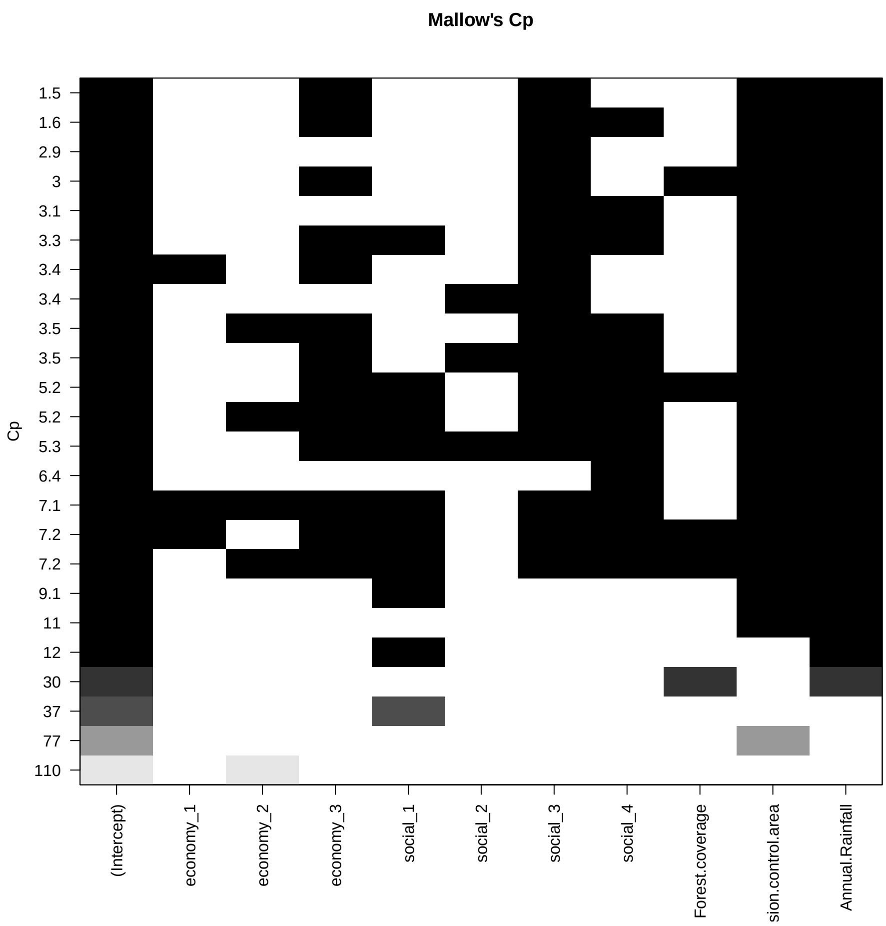

Figure 20: Mallow's Cp

```
> SignifReg(nullmodel,alpha = 0.10, criterion = "r-adj",scope = scope,direction = "both")

Call:
lm(formula = response ~ social_1 + Annual.Rainfall + Social.erosion.control.area,
    data = beijing.pca_data)

Coefficients:
                (Intercept)                     social_1              Annual.Rainfall  Social.erosion.control.area
                    0.65526                      0.06223                      0.05529                      0.06156

> SignifReg(nullmodel,alpha = 0.10, criterion = "PRESS",scope = scope,direction = "both")

Call:
lm(formula = response ~ social_1 + Annual.Rainfall, data = beijing.pca_data)

Coefficients:
    (Intercept)         social_1  Annual.Rainfall
        0.65526          0.12610          0.04582
```

Figure 21: Stepwise

Since the main goal of this part is to find the relationship between variables as well as how these variables affect the coherence, we choose the results of adjusted R^2. Using the selected variables from stepwise, we can construct a new model.

```
Call:
lm(formula = response ~ social_1 + Annual.Rainfall + Social.erosion.control.area,
    data = beijing.pca_data)

Residuals:
     Min       1Q   Median       3Q      Max
-0.11210 -0.01343  0.00799  0.01541  0.05362

Coefficients:
                            Estimate Std. Error t value Pr(>|t|)
(Intercept)                 0.655258   0.008461  77.443  < 2e-16 ***
social_1                    0.062234   0.034811   1.788 0.091650 .
Annual.Rainfall             0.055288   0.011118   4.973 0.000116 ***
Social.erosion.control.area 0.061556   0.032146   1.915 0.072486 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.03877 on 17 degrees of freedom
Multiple R-squared:  0.9524,    Adjusted R-squared:  0.944
F-statistic: 113.3 on 3 and 17 DF,  p-value: 1.943e-11
```

Figure 22: Stepwise Summary

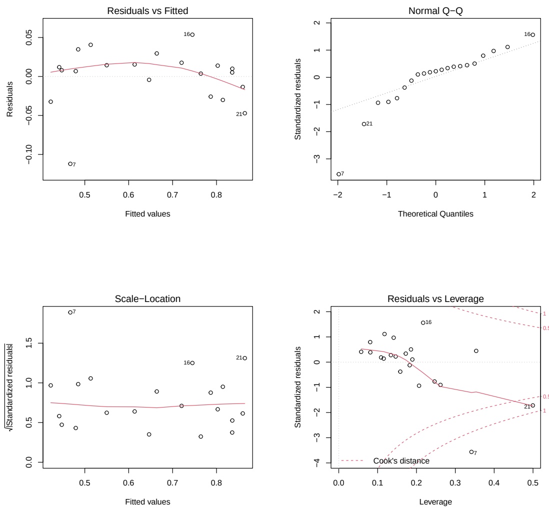

Figure 23: Stepwise Diagnose

From the summary table, it seems that all variables are significant and R^2 reduces to 0.9524, which is tolerable. From the diagnostic plots, it seems that the variance becomes constant but with little left-skewness. Also, there still might be non-linear relationship, suggesting the introduction of transformation.

We hereby use Box-Cox transformation, and here is the result.

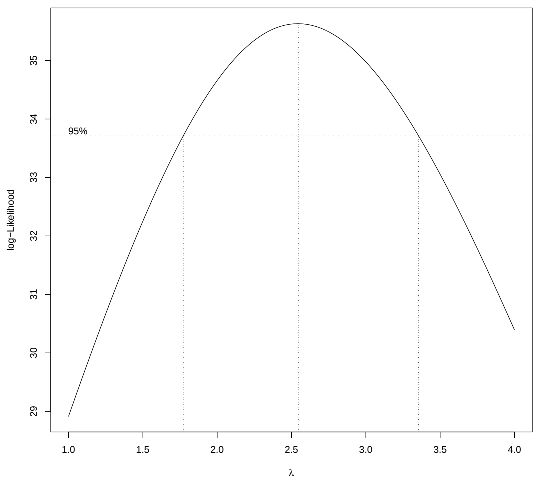

Figure 24: Box-Cox Transformation

However, we decided not use the result of transformation for two reasons. First, since we have little domain knowledge, we cannot explain why such λ is appropriate. Hence, such model could be hardly interpreted, which obstructs us from finding the proper relationship between variables and coherence. Second, the sample size is rather small, hence the cause of non-linearity could be randomness. To summarize, we need more data and more domain knowledge to support such transformation.

5 Other fit methods

5.1 Lasso

Lasso is a widely used method to automatically select the variables and have a good performance in prediction. The loss function and its equivalent is:

$$Q(\beta) = \|y - \boldsymbol{X}\beta\|^2 + \lambda\|\beta\|_1$$
$$\iff \quad \arg\min \|y - \boldsymbol{X}\beta\|^2 \text{ s.t.} \quad |\beta_j| \leq s$$

As above, we use the original data in Beijing as predictors, the coherence score in Beijing as response variables. Using Leave-One-Out method and mean square error as loss function, we try different lambda to determine the best hyper-parameter. The result is :

$$\lambda = 0.00015 \tag{12}$$

$$\sqrt{MSE} = 0.029 \tag{13}$$

The result is generally better than traditional the linear regression method.

5.2 XGBoost

XGBoost, which stands for Extreme Gradient Boosting, is a scalable, distributed gradient-boosted decision tree (GBDT) machine learning methods. Compared with linear models such as multiple linear regression and Lasso, XGBoost may discover nonlinear relationship between the predictors. As above, we use the original data in Beijing as predictors, the coherence score in Beijing as response variables. This time, both the maximum depth and max weak learners are hyper parameters. Using the grid search method and Leave One Out validation. The result is:

$$max\_depth = 1, max\_estimators = 160 \tag{14}$$
$$\sqrt{MSE} = 0.0045 \tag{15}$$

The result is worse than the linear regression model, which may indicate that linear relationship dominate the correlation between predictors and response variables.

6 Prediction of coherence: Using time series method

Since the predictors of the future years are unavailable, so we cannot use the above fitting methods to get the prediction. Instead, we seek for time series feature in order to figure out the trends.

The series is not stationary until we differentiate the series twice, the adf-test result is:

$$adf_statistic = -3.35 \tag{16}$$

$$p\_value = 0.012 \tag{17}$$

For the stationary series, we use the BIC criteria to determine the order of the model. So the result is:

$$ARIMA(0,2,1), BIC = -37.57 \tag{18}$$

Fit the model, we can get the parameter as well as the diagnosis of the model. Ljung-Box test regard the residual as white noise, the normal qq plot discovers one outlier in the residual, and residual plot indicates no correlation between residuals. the diagnosis plots is shown in the figure below: Since the model gives no information if the forecast period is above 2, we

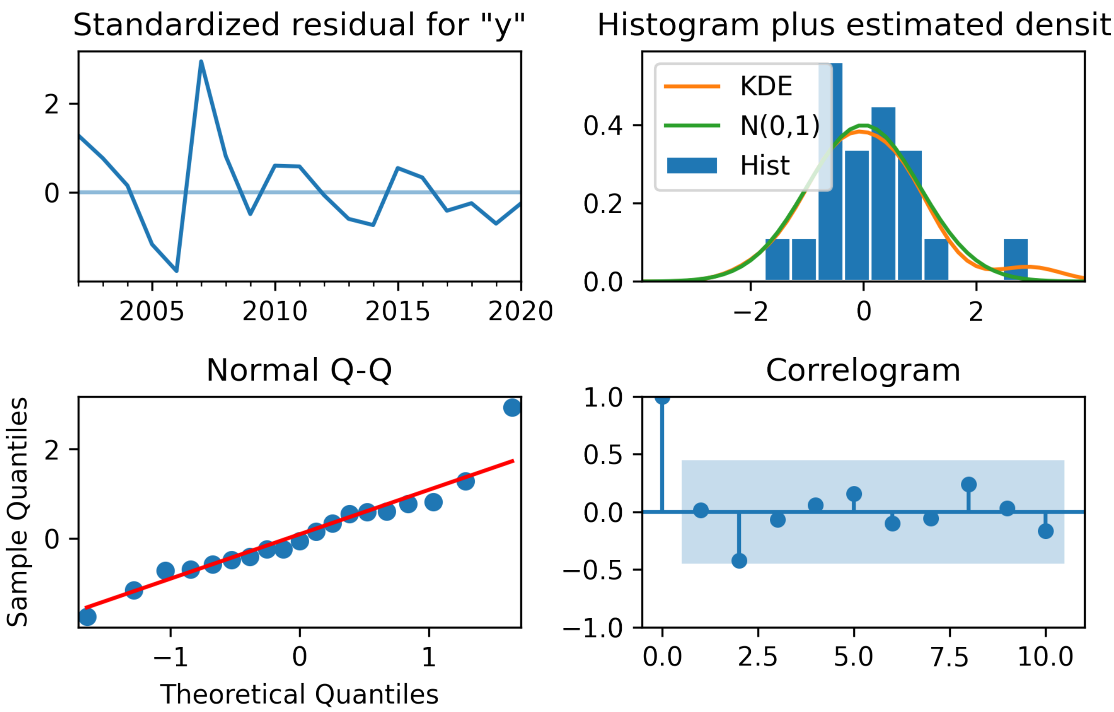

Figure 25: Time series diagnosis plot

simply get two year prediction using the model, the result in shown in the figure.

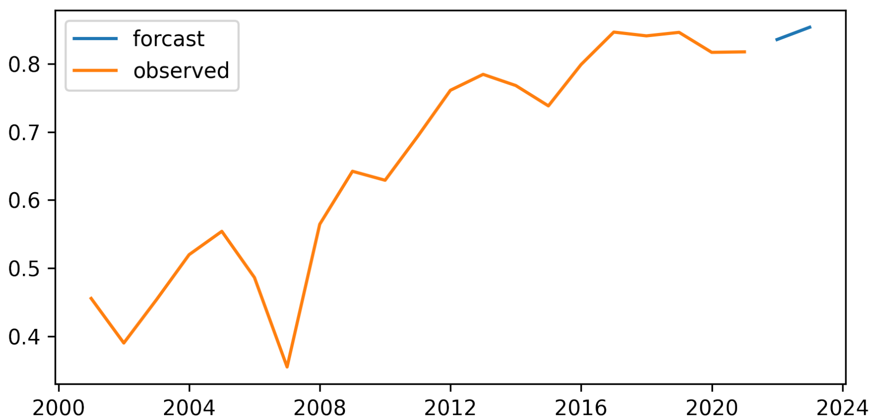

Figure 26: prediction for the coherence score

7 Regional Distribution of Development of Wildlife Habitats

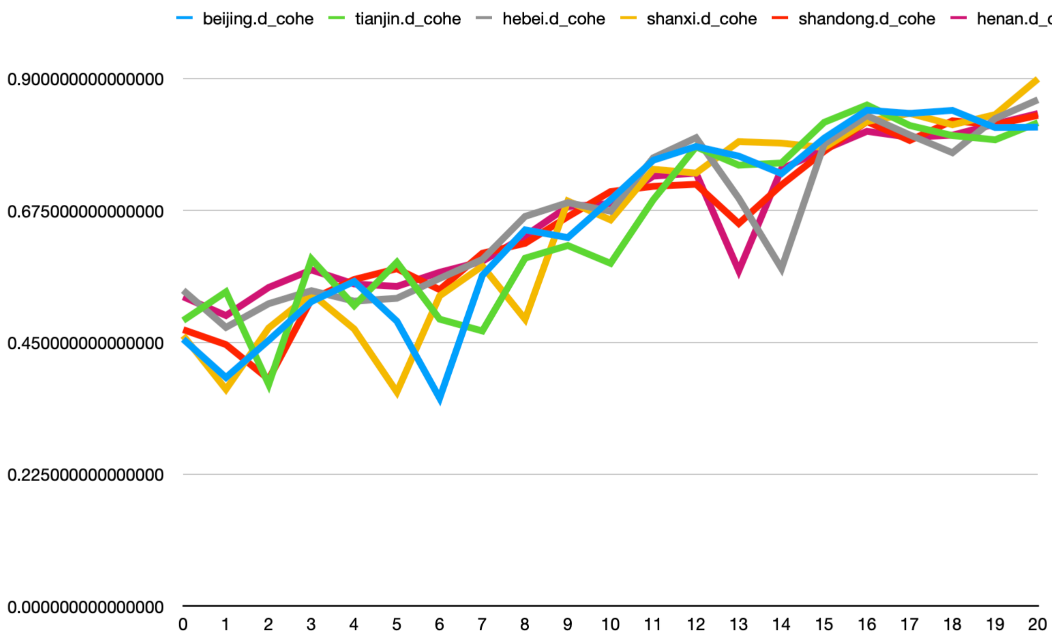

Figure 27: Coherence of six Provinces

From the plot above, we can see that the trends of all six provincial coherence are upwards, which is intuitive because the government has utilizes a series of methods to improve environment since 2012. We can also see that there are synchronized drops around 2006 and 2014. This is probably because around such years, some high-pollution industries developed rapidly such as steel industry. Also, the economy developed faster than the improvement of ecology, causing the coherence to drop a little.

Using the coherence score as indicator, we can derive the regional distribution of habitat in certain periods. For comparison, we calculate the coherence score in the above-mentioned six provinces during the year 2000,2005,2010, 2015,2019, the figures is shown below.

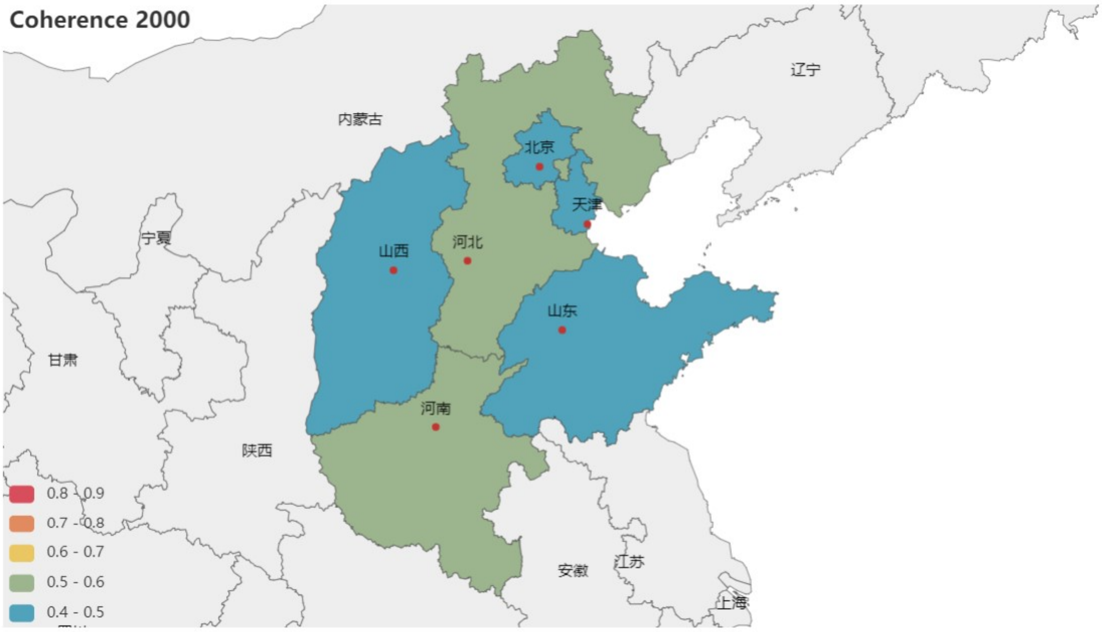

Figure 28: coherence in 2000

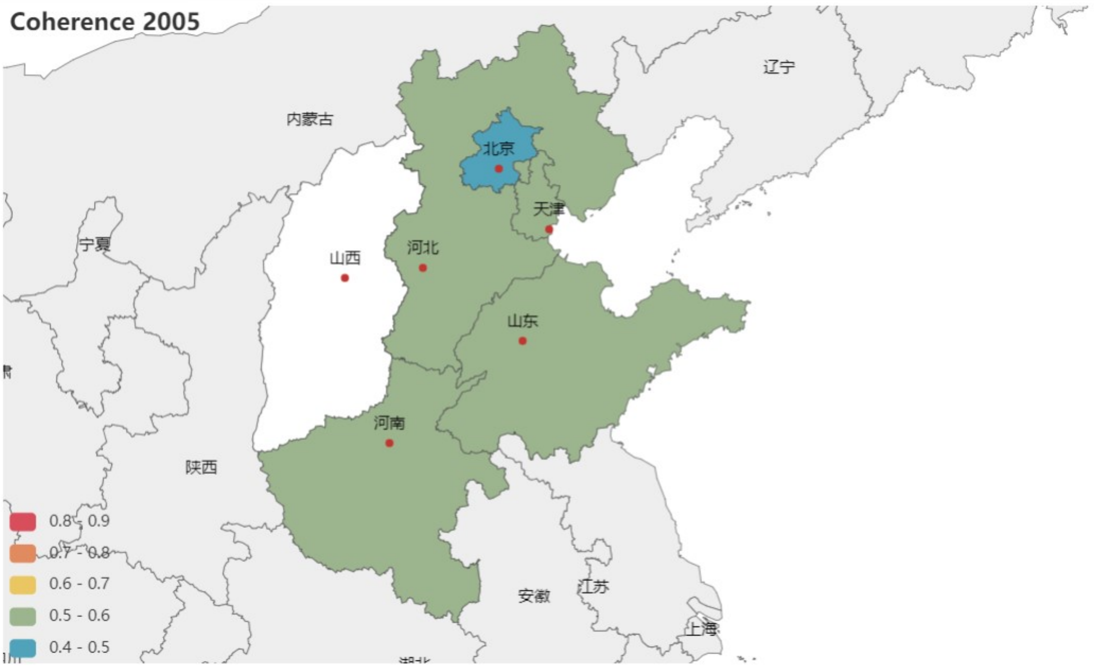

Figure 29: coherence in 2005

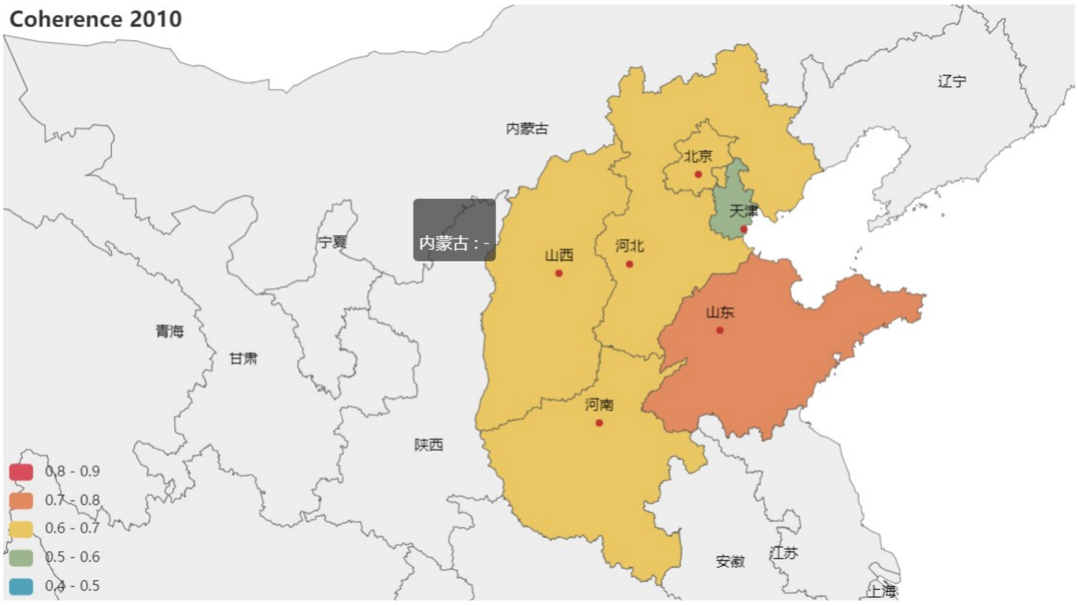

Figure 30: coherence in 2010

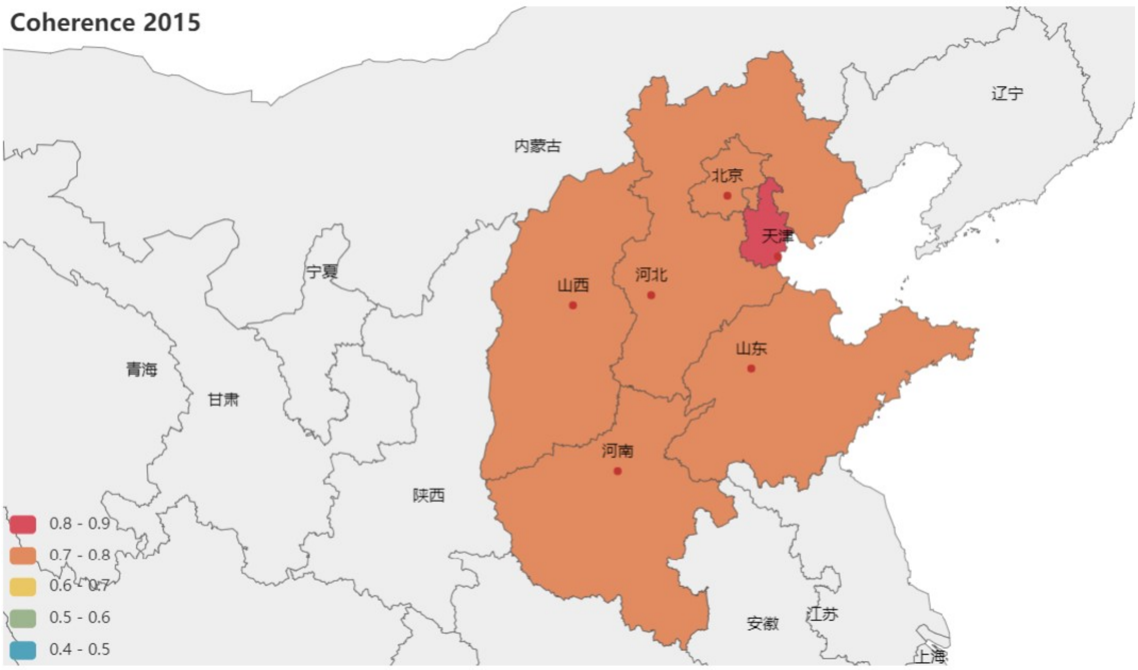

Figure 31: coherence in 2015

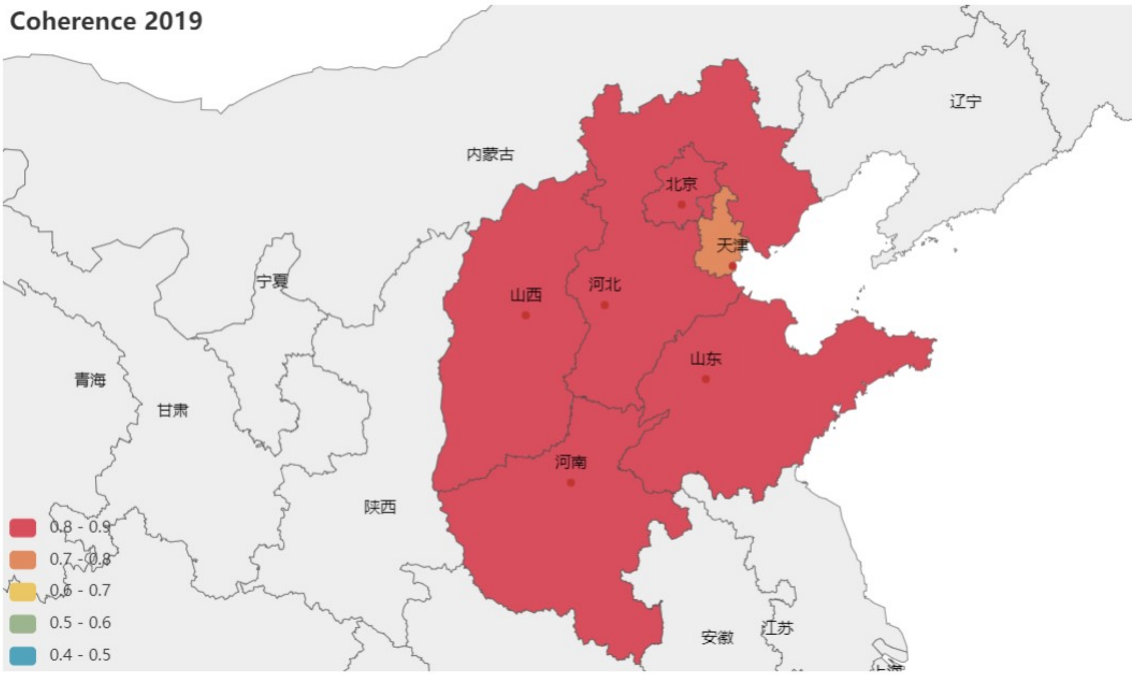

Figure 32: coherence in 2019

8 Conclusion

8.1 Review of the Research

From the empirical research, we can observe a considerable increase of coordinated development level during the recent years, though there are years which the coherence score is decreasing. Much of our models fit the data decently, and Leave-One-Out validation approach prevent overfitting in the models, giving our models a good competence in prediction. Time series model performs not good in this case, probably because of lack of considerable time-dependent trend in the coherence scores. Regional distribution gives the difference between regions, but the above-all trend of coherence trend increases with time.

8.2 Limitations

Due to lack of domain knowledge and source of data, a few limitations exists. First, the entropy weight method exclude subjective influence, but fail to consider the priori from domain knowledge. Second, much of our data is missing. Though we fill the matrix, we cannot compensate for the information missing. The sample size is small, which may result in lack of fit of models. Third, the evaluation system of habitats and coordinated development is simple, which may not comprehensively represent the real situation.

8.3 Variable Interpretation

Using Multilinear Regression methods, we discovered that variables pertaining to society and ecology have greater influence on coherence. The variables pertaining to ecology such as Annual.Rainfall should be crucial since the response we are considering is associated with ecological renovation. Hence, variables like Water.Erosion can partly represent such progress in renovation.

The variables pertaining to society are rather not easy to interpret. However, if take the fact, that ecological renovation needs labor and capital, into consideration, such relationship is conspicuous. Only with high social score and high economical score can a supreme ecological renovation be available. Also, it might not be intuitive that economical variables are not included. Nonetheless, since social variables include the information such as Unemployment.Rate, which can partly represent the economical score, so stepwise method may delete economical variables for simplicity.

8.4 Policy Suggestion

According to the analysis we made, we hereby put forward the following suggestions:

1. Economical development should be put at the top of the list. Since economical development can increase the income of people, causing good results such as more people to coming to such places, which can increase the social score further. Also, economical development can provide more capital to renovate the ecosystem.

2. Using methods like propaganda to appeal to more people into ecological renovation. Since social variables are considered significant by stepwise, there is no doubt that such strong relationship is valid. Hence, the government should call for more people to renovate ecosystem. For instance, a pay raise in industries like fishery, forestry or health institution can appeal to more people.

3. Governments put more funds and labor into ecological renovation.

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