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T1 ________________	**1923519**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

2019
MCM/ICM
Summary Sheet

A Method to calculate INVISIBLE COST

Summary

In recent years, environment has suffered a lot due to the occurrence of environmental degradation. People are aware of the importance of environment protection and the position of mankind in nature. Economists develop Green GDP in order to consider the invisible environmental costs in economic activities. Human beings actually play an important part in a natural socio-economic complex ecosystem. Hence the evaluation of ecosystems services as well as the true cost of environment is of great gravity.

To answer this question, we collect ESV (Ecosystem service value) data based on Constanza method and LUCC (Land-Use and Land-Cover Change), using the China Terrestrial Ecosystem Unit Area Ecological Service Value Equivalent Factor Table. Inspired by the PSR (Pressure State Response) model, an ETC (Environmental True Cost) model is established, which considers environmental costs as responses under ecological stress. Environmental cost is the cost people spend to balance or regulate the normal state of the ecosystem. In a short period of time, the EC (environmental cost) should coincide with a part of the ecosystem service value variable. During a long period, under the adjustment of the ecosystem, the environmental cost should be included in the change of the value of ecosystem service, and gradually coincide with it. Therefore, we establish the EC-ESV coupling model to calculate the correlation coefficient. The ESV is used to represent the EC and is substituted into the ETC model, which simplifies the calculation of the Environmental True Cost. We analyze the Environmental True Cost Value to verify the validity of the model by taking Hebei Province as an example.

In the next section, we use the change in Expenditure GDP (dGDP) as the cost of human economic activities. Taking Lanzhou as an example, we use the forward stepwise regression method to establish the relationship between GDP and the ecosystem service value of six land types. The impact of ecosystem service values of various land types on GDP indirectly reflects the relationship between the change in ecosystem service value and environmental cost. In this part, we offer some suggestions to policymakers.

In the case of Shandong Province, we use the time series data of atmosphere, solid waste, water pollution to connect with GDP. Based on PCA (principal component analysis) method, we propose two comprehensive components of environmental pollution indicators as an explanatory variable. We establish a multivariate regression model reflecting the relationship between environmental costs and GDP.

To conlude it, we manage to response the tasks through the cases of three areas in China. Our series of models is capable of evaluating the true cost of land disgradation, especially avoiding duplicated counting problem. However, due to the characteristics of different areas, our own model has its own limitation and we suppose an ideal method for future improvement.

Keywords: ecosystem services; valuation; monetary; coupled ecological-economic model

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January 29, 2019

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Contents

1 Introduction

1.1 Problem background

Economists have been focused on quantifying and analyzing the tangible benefits of goods and services since Adam Smith times, where the value of ecosystem services(ES) tended to be 'invisible'.

A large number of existing indicators and models (regression models, biophysical evaluation models, GIS-based models, etc.) still have many shortcomings in the process of evaluating UES due to its non-monetary characteristics. Most cases focus on UES at a certain point in time without considering time changes. In addition, many studies are currently focused on a single or a limited number of UES. Hence, there is an urgent need for a comprehensive evaluation method.

1.2 Our efforts

The core concept of our model is to take the changes of ecosystem services into consideration. The first job is to classify different land types based on GIS system and quantification different services related to our welfare with a logical method. The second job is to find the equation between ESV and TEC. Motivated by Robert Costanza(1997) 's contribution in the evaluation of global value of ecosystem services, we establish a series of models to calculate the true cost of environmental degradation caused by land use project and realize many other functions.

We regard EC as a response to ESV and reveal the relationship between them as ***Figure.1*** to help readers better understand the logic of our model.

In addition, we come up with a ESV-EC coupling method to calculate the true cost of land degradation of an area. Hence we can turn the tremendous EC-related factors into the changes in land type.

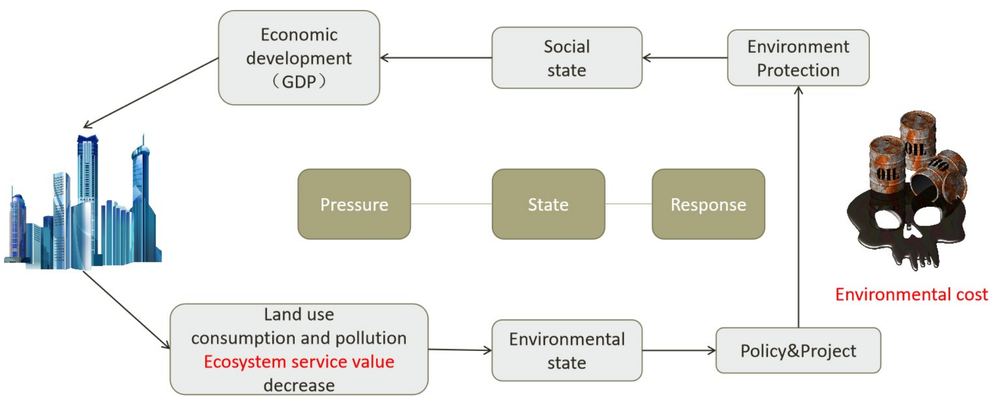

Figure 1: PSR model

2 Notation

We use the notation in Table 1 to present the indicators in equations of our Model.

Table 1 Notations

Symbol	Definition
ESV	Ecosystem services value($/a)
EC	Envrionmental cost
TC	True cost of an area during a period
$dGDP$	The change of GDP during a period
$dESV$	The varity of ESV due to land types' changes
$EESV$	The sum of ESV of different land types and their areas
aEC	The total of EC during a period
UES	Urban ecosystem services

3 Assumption

We make the following assumptions for the Model:

- The cost of environment is not all included in the GDP of a region.
- The economic activities of the region are strongly connected with the utilization of land.
- The consequences of land degradation will revenge on humanity immediately neglecting the time lag.
- The ecosystem services valuation is only determined by the type of land regardless of the area(ha) or other property of the land.
-

4 Statement of our Model

4.1 Ecosystem services value

$$ESV = \sum(Q_j * VS_j) \tag{1}$$

$$ESV = \sum(A_k * VC_k * L * \frac{EF_k}{EC_k}) \tag{2}$$

$$L = \frac{1}{1 + e^(3 - 1/En)} \tag{3}$$

Q–quantity of ecosystem services

VS–valuation of ecosystem services

A_k–area(ha)

VC_k–Ecosystem value coefficient

L–Social development stage coefficient

En–Engel coefficient

k–land category

EF_k–Ecological footprint

EC_k–Ecological capacity

4.2 Environmental True Cost model

The title of this subsection is the key of our model. Traditionally, 'bottom-up' and 'top-down' are the two basics methods for calculating the cost of a project. It is apparent that it is a challenge to do the accumulating job. So we regard the invisible cost as the Environmental cost.

$$TC = dGDP + EC \tag{4}$$

$dGDP$–the amount of change in GDP during a period

4.3 ESV-EC coupling

The classes of ecosystem services are divided into four Primary Types as concluded in ***Table*** 2. Compared with equation(5) below, the judging criteria ESV and EC is duplicated to some extent, as shown in ***Figure*** **2**.

Table 2 Classification of ecosystem services

Primary Type	Subsidiary Type	Definition
Supply service Type	Food	Convert solar energy into food
	Raw material	Convert solar energy into bioenergy
Adjustment service	Gas	Maintain atmospheric chemical composition
	Climate	Regulating regional climate
	Hydrology	Storage and supply of fresh water
	Waste	Decomposition process
Support service	Soil	Nutritional cycle
	Biodiversity	Survival and Evaluation
Culture service	landscape aesthetics	Potential entertainment

$$EC = \sum(EL_i * UEC_i) \tag{5}$$

$$EL_i * UEC_i = EC * \beta_i \tag{6}$$

$$dESV = \sum EC * \beta_i + D \tag{7}$$

$$dESV = N * EC + D \tag{8}$$

EL–Environmental load

UEC–Unit cost of Environmental load

N–the conversion coefficient of EC and the twice counted part

D–the value of the additional function which is unnecessary to be calculated into true cost.

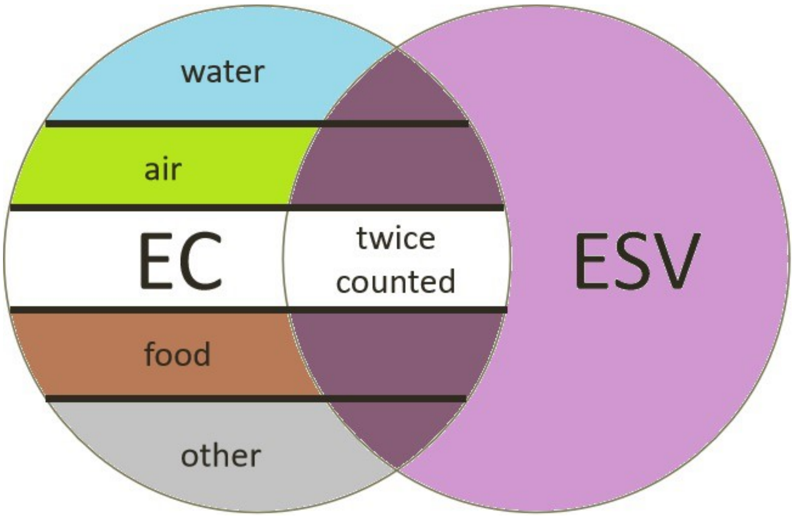

Figure 2: EC-ESV coupling

In a large area such as a city or a country, it is difficult to calculate EC in a static model but based on the method of Robert Costanza we can analyze the ESV of a certain area. Hence the form of equation (3) become:

$$TC = dGDP + \frac{dESV - D}{N} \tag{9}$$

$$TC = dGDP + \frac{\sum(A_k * VC_k * L * \frac{EF_k}{EC_k}) - D}{N} \tag{10}$$

We use the research of Gaodi, Xie(***Table 3***) as reference to make our model correspond to the actual situation of China.

Table 3 The values per unit area of ecosystem services in China$(yuan * hm^-2 * a^-1)$,2007

Primary Type	Subsidiary Type	Woodland	Grassland	Farmland	Wetland	Water	Desert
Supply service Type	Food	148.20	193.11	449.10	161.68	238.02	8.98
	Raw material	1338.32	161.68	175.15	107.78	157.19	17.96
Adjustment service	Gas	1940.11	673.65	323.35	1082.33	229.04	26.95
	Climate	1827.84	700.60	435.63	6085.31	925.15	58.38
	Hydrology	1836.82	682.63	345.81	6035.90	8429.61	31.44
	Waste	772.45	592.81	624.25	6467.04	6669.14	116.77
Support service	Soil	1805.38	1005.98	660.18	893.71	184.13	76.35
	Biodiversity	2025.44	839.82	458.08	1657.18	1540.41	179.64
Culture service	landscape aesthetics	934.13	390.72	76.35	2106.28	1994.00	107.78
	Total	12628.69	5241.00	3547.89	24597.21	2366.69	624.25

5 Validating the Model & Respongding to tasks

5.1 Hebei Province, China

Human economy and society are part of nature. Material and energy cycle in a socio-economic-natural complex ecosystem.

Hebei Province is a provincial administrative region of People's Republic of China. Shijiazhuang, the provincial capital, is located in North China, with a boundary between 36′05′-42′40′ north latitude and 113′27′-119′50′ east longitude. It is surrounded by the capital Beijing, east and Tianjin are adjacent to the sea. The total area of Hebei Province is 188,800 square kilometers.

At the end of 2017, the resident population of Hebei Province was 75,195,200, achieving a GDP of 359.64 billion yuan, an added value of 350.79, 1,741.65, 1503.96 billion yuan in the primary industry, secondary industry, and the tertiary industry. The GDP per capita reached 47,985 yuan.

We apply our model in this area.

$$ESV = \sum(A_k * VC_k * L * \frac{EF_k}{EC_k})$$

$$\sum dESV = N * EC + D$$

$$TC = dGDP + \frac{dESV - D}{N}$$

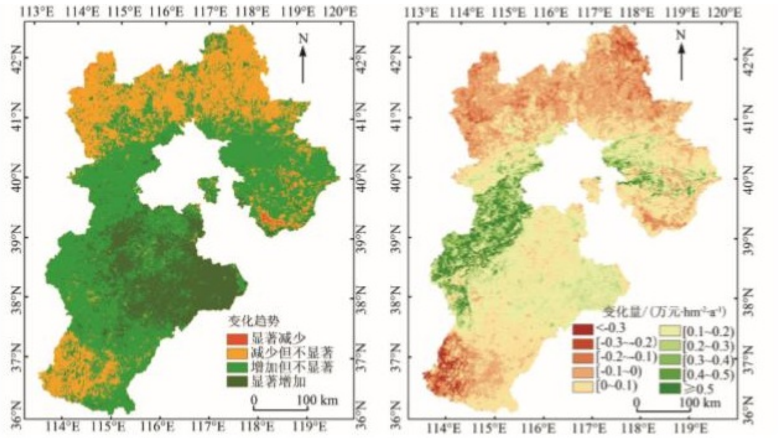

Figure 3: Variable(left) trend and variation(right) of ESV of Hebei province, 2000-2009

Table 4

Year	ESV	aEC	EESV	EC	dESV	GDP
2001	1.7	3543.43	3139.9	403.53		5577.78
2002	1.67	3607.51	3084.49	523.02	107.78	157.19
2003	2.2	3599.42	4063.4	-463.98	978.91	7098.56
2004	2.13	3877.05	3934.11	-57.06	-129.29	8768.79
2005	1.94	4058.72	3583.18	475.54	-350.93	10096.11
2006	1.65	4200.06	3047.55	1152.51	-535.63	11467.6
2007	1.89	4271.52	3490.83	780.69	443.28	13607.32
2008	2.16	4667.48	3989.52	677.96	498.69	16011.97
2009	1.8	4852.7	3324.6	1528.1	-664.92	17235.48

In this case, the variety of ecosystem service value is negatively correlated with environmental cost. The lower the EC is, the higher the ESV, which illustrates that EC of Hebei is contributed by environment governance mostly. This result is coincident with the actual situation of Hebei–a extensive economic growth model.

During this period, the increase in GDP of Hebei Province is 1155.77 billion yuanthe variety of ESV is +184.7 $(yuan*hm^-2*a^-1)$ EC=502.03 billion yuan , TC=dGDP+EC=1657.8 billion yuan. In conclusion, the true cost of land degradation in Hebei during 2000-2009 is 1657.8 billion yuan.

5.2 Lanzhou

5.2.1 Stepwise regression

In statistics, stepwise regression is a method of fitting regression models in which the choice of predictive variables is carried out by an automatic procedure. In each step, a variable is considered for addition to or subtraction from the set of explanatory variables based on some prespecified criterion. This process goes through several steps until no new variables can be introduced. At this time, all variables in the regression model are significant.

5.2.2 Application

Lanzhou is the capital of Gansu Province, an important industrial-based city in northwest China. The city is located at 36′03′ north latitude and 103′40′ east longitude. It is about 35 km from east to west and 2 to 8 km from north to south. It has Wulan Mountain in the south and Beishan in the north. The total area of the city is about 131,000 km2, of which the urban area is about 1631.6 km^2. Most places are between 1,500 meters and 3,000 meters above sea level. The climate varies greatly from place to place, and the ecological environment is complex and diversified. We select the value of ecosystem services and relevant data in Lanzhou City from 2005 to 2009, and conduct forward-stepwise regressionto obtain the relationship between GDP and the ecosystem service value types. The model has passed the significance test.

Table 5 ESV of different land types

Year	Farmland	Orchard	Woodland	Grassland	Water	Unused land	ESV	GDP
2005	8.66	0.76	53.82	87.24	25.47	0.72	176.67	567.04
2006	10.86	0.69	55.7	80.25	13.2	0.71	161.41	638.47
2007	8.63	0.77	61.35	90.97	14.87	0.71	177.31	732.76
2008	8.74	0.63	54.03	115.24	12.98	0.7	192.31	830.02
2009	9.28	0.73	59.82	121.09	13.78	0.7	205.41	920.11

$GDP = 5.568 * Farmland + 10.660 * Woodland + 4.336 * Grassland - 6944.763 * Unusedland + 4567.101$

Except the less relevant Orchard and Water land types, among the six types of land types, the most important indicators on economic growth are forest land and unused land. The ESV of forest land is superior to other land types so to promote economic growth while increasing the value of urban ecosystem services, more land project for woodland should be considered by government.

5.3 Shandong Province

5.3.1 Principal Component Analysis

The model construction steps of Principal Component Analysis are as followed:

Step one: Determine analytical variables and collect data. We assume that the matrix of n samples from original observational variables is :

$$\begin{Bmatrix} X_{11} & X_{12} & X_{1p} \\ X_{21} & X_{22} & X_{2p} \\ X_{n1} & X_{n2} & X_{np} \end{Bmatrix}$$

Step two: (1) Standardize the transformation of the raw data. The standardized transformation of the raw data is to eliminate some unreasonable effects that may be caused by the difference in dimensions. The SPSS system can automatically perform standard conversion. (2) Calculate the correlation coefficient matrix, and the calculation formula is:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{1p} \\ r_{21} & r_{22} & r_{2p} \\ r_{n1} & r_{n2} & r_{np} \end{bmatrix}$$

r_{ij} is the corelation coefficient of r_i and r_j; r_{ij}=r_{ji}

The calculation formula is:

$$r_{ij} = \frac{\sum(x_{ki} - \overline{x}_i)(x_{kj} - \overline{x}_j)}{\sqrt{\sum(x_{ki} - \overline{x}_i)^2 \sum(x_{kj} - \overline{x}_j)^2}}$$

(3) Calculate the feature values and feature vectors and arrange in order of the feature values from largest to smallest. The characteristic equation for solving the eigenvalue λ is $|\lambda I - R| = 0$, the formula for solving the eigenvector ei(i=1,2, ...,p) is:

$\sum e_{ij} = 1$

(4) Calculate the contribution rate and cumulative contribution rate of each component, and extract the number of principal components. Generally we require cumulative contribution rate at 75%-85%.

Contribution rate of each component=$\lambda_i / \sum \lambda_i$

Cumulative contribution rate=$\frac{\sum_{k=1}^{i} \lambda_k}{\sum_{k=1}^{p} \lambda_k}$

(5) Calculate the principal component load matrix, use the formula below

$l_{ij} = p(z_i, x_j) = \sqrt{\lambda_i * e_{ij}}$

and get K principal component load matrices as:

$$L = \begin{bmatrix} l_{11} & l_{12} & l_{1k} \\ l_{21} & l_{22} & l_{2k} \\ l_{p1} & l_{p2} & l_{pk} \end{bmatrix}$$

Step three: Get the model. (1)Each principal component score model. (2)Integrated score model.The proportion of each principal component contribution of the sum of the cumulative contribution rates of the principal components is used as the weight.

$F = \sum w_i F_i$

$w_i = \frac{\lambda_i}{\sum_{i=1}^{k} \lambda_i}$

5.3.2 Application

Shandong, is a provincial administrative region of the People's Republic of China. Jinan, the provincial capital, is located on the eastern coast of China. The boundary between Shandong Province is 34'22'-38'24' north latitude and 114'47'-122'42' east longitude. It borders Hebei, Henan, Anhui and Jiangsu provinces from north to south. Shandong Province has a total area of 157100square kilometers.
As of the end of 2017, the resident population of Shandong Province was 100.05 million and the regional GDP was 7277.8 billion yuan, the primary industry was 487.67 billion yuan, the secondary industry was 3292.51 billion yuan, and the tertiary industry added value was 3487.63 billion yuan. The total value is 72,851 yuan.

Table 6 Environmental indicators data of three wastes and soil erosion

Year	Wastewater	SO_2	Soot	solid waste	SO_2 actual	GDP	Soil erosion governance area
2001	115933	172	65	6215	141.95	9195.04	3454.7
2002	106668	169	62	6559	135.54	10275.5	3558.4
2003	115933	184	62	6786	140.78	12078.15	3645.76
2004	128706	182	52	7922	135.17	15021.84	3717.2
2005	139071	200	62	9175	145.2	18366.87	3786.99
2006	144365	196	58	11011	112.03	21900.19	3892.34
2007	166574	182	46	11935	103.67	25776.91	3971.26
2008	176977	169	44	12988	73.01	30933.28	4489.49
2009	182673	159	42	14138	58.48	33896.65	4593.19
2010	208257	154	39	16038	50.54	39169.92	4651.5
2011	187245	183	78	19533	67.22	45361.85	4722.49

Sample selection and data sourcesThis paper selects the environmental indicators of the three wastes and soil erosion in Shandong Province from 2001 to 2011, and concludes the indirect relationship between environmental pollution and economic growth.

SPSS software was used as a statistical analysis tool to perform principal component analysis on the above variables. The validity of principal component analysis, the eigenvalues and contribution rates of each component, the principal component load matrix, and the regression model are constructed.

Table 7 KMO and Bartlett's test of sphericity

Kaiser-Meyer-Olkin measure of sampling adequacy		.718
Bartlett's test of sphericity	Approx. Chi-Square	124.905
	Degree of freedom	21
	significance	.000

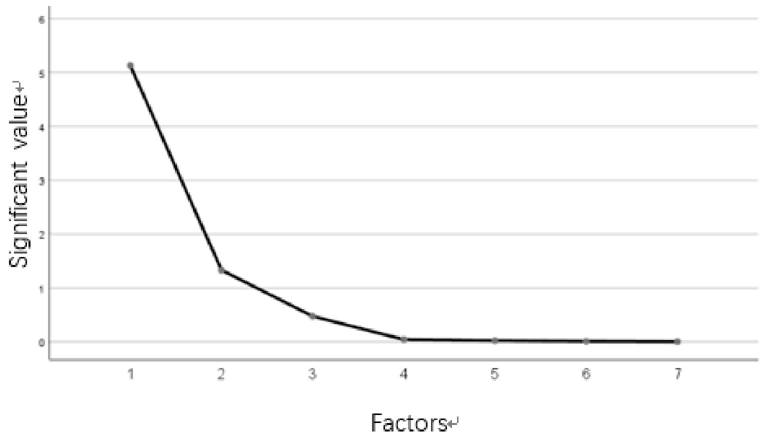

Figure 4: Scree plot

Table 8 Component matrix

	C1	C2
Industrial waste water emssion	.980	.039
SO_2 emission	-.523	.696
Soot emission	-.436	.778
Industrial solid waste	.936	.345
Industrial solid waste utilization	.944	.322
SO_2 actual emission	-.988	.071
soil erosion governance area	.981	.110

$F1 = \sum C1 * Indicatordata$— Indicating water and soil pollution

$F2 = \sum C2 * Indicatordata$— Indicating air Pollution

$$GDP = 11812.072F1 + 3224.907F2 + 23816.018 \tag{11}$$

Shandong Province is also an extensive economic development model. Water and soil pollution is highly correlated with economic development, and the economy is developed at the expense of ecosystem services. In addition, its soil erosion control is also positively related to economic growth.

6 Conclusions

6.1 A summary

In conclusion, we manage to response the tasks through the cases of three areas in China. Our series of models is capable of evaluating the true cost of land disgradation, especially avoiding duplicated counting problem. However, due to the characteristics of different areas, our own model has its own limitation and we suppose an ideal method for future improvement.

6.2 The theory of idealized new evaluation method

Our model is capable of evaluating the Environmental True Cost of a certain city. However, the current model lacks a transformation method between different areas. We suppose that in the future we can introduce Multi-criteria Analysis to scale and range each variable and aggregate through a weighted optimization process.

$$Y = TC * k \tag{12}$$

Y–the environmental true cost of a certain city.

k–a transformation coefficient based on Big Data

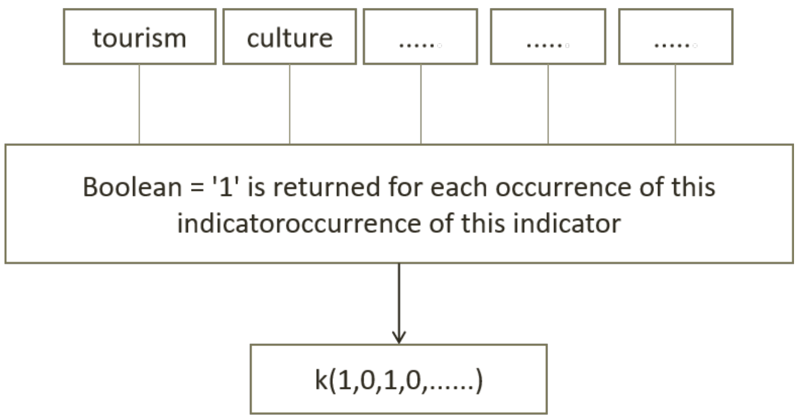

Figure 5: A schematic diagram of this theory

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