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The Influence of Spectrum Resource Optimization Allocation on Economic Growth Oriented to the Information Maturity

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ABSTRACT With the rapid development of information and communication technology (ICT), a higher demand is put forward for the optimal allocation of radio spectrum resources carrying core ICT applications, include in the fields of intelligent manufacturing, transportation and public utilities and so on. The influence of optimal allocation for radio spectrum resources on economic growth is increasingly being widely attention. In this paper, we analyze the influence and contribution of optimized allocation of radio spectrum resources on economic growth. An impact index system of spectrum resource allocation on economic growth is built based on information maturity. Then, the index of key influence factors is extracted by the rough set theory. Moreover, the influence and contribution of optimal allocation of radio spectrum resources on economic growth are analyzed by Cobb-Douglas (C-D) production function. The results show that the influence and comprehensive contribution of spectrum resources optimal allocation on economic growth (GDP) are fitted, based on the indirect impact of ICT on various industries/industries, using actual economic growth data from 2008 to 2017. The proposed method provides a scientific basis and decision support for optimal allocation of spectrum resources in the future. Meanwhile, the conclusion has theoretical and practical significance to promote the progress of ICT and the development of social economy.

INDEX TERMS Optimization allocation, information maturity, rough set, C-D production function.

I. INTRODUCTION

As a reusable and irreplaceable natural resource, radio spectrum resources are widely used in economy, society, military and so on [1]. While it become an important part of national economic growth as mineral resources, rivers, land resource gradually [2]. The radio spectrum resources are regarded as Commons [3], and the spectrum users can trade the right to use resources in the market [4], or share the spectrum resources in complying with technical standards [5]. In recent years, those new concepts have emerged, such as "Internet of things", "Industry 4.0", "smart city", "intelligent transportation" and so on. So the application demand of information and communication technology (ICT) is increasing in the fields of industry, transportation and public utilities, which puts forward higher requirements on the optimal allocation of radio spectrum resources carrying core technologies [6], [7]. However, it is still difficult to obtain the influence and contribution of spectrum resources on the economy from the Co-created value [8].

Research on the impact of radio spectrum allocation to economic has been carried out for many years. Nobel laureate in economics, Ronald H. Coase, on behalf of the experts and scholars, put forward that "spectrum must be regarded as another kind of production factors, and its value must be confirmed in a free market". This insight has been known as the "Coase theory" [9]. Then the radio spectrum resource is regarded as production factors, those researchers

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explore its market value and economic influence, and provide theoretical support for the economic growth policies of governments [10]. Base on those research results, Xiaoli *et al.* proposed a multiple regression analysis using the Cobb-Douglas production function, and make an empirical analysis on the contribution of optimal allocation for radio spectrum resources to economic growth [11].

Britain is the first country in the world to study the relationship between the allocation of radio spectrum resources and national economy, and the economic impact in optimal allocation of radio spectrum resources is measured [12]. Then two classical quantitative estimation methods of economic benefits emerge in the Report – The Economic impact of the Use of Radio in the UK, published in 1995 and subsequently updated with last update in March 2006. The methods calculate the contribution of radio use to the economy using: one is gross domestic product (GDP) and employment; the other is consumer and producer surplus [13].

The use of the GDP method to estimate the economic benefits is based on the contribution of radio makes to all business activity within a country. In practice GDP and employment contributions may enter the economy at a number of different points that are determined by the operation of the particular service. Once the GDP and employment figures have been adjusted to take into account the displacement effects, the impact of ''multiplier effects'' can be considered. Multiplier effects arise from the impact of wages and profits, generated in all businesses associated with the use of radio, as they spread through the rest of a country's economy and in the process create further income and employment. On the other hand, the total surplus is taken into account in the method of consumer and producer surplus, which arising from the use of radio would be equal to the summation of the consumer and producer surplus for each service. The advantage of the consumer and producer surplus method is that it accounts for the impact of the wider displacement effects. In addition, the demand and supply curves can be useful for displaying the costs and benefits of a particular use of radio spectrum resource.

Under the optimal allocation of radio spectrum resources, and the effective use of ICT in the economy and society, the effect of spectrum allocation on employment and welfare can be increased significantly in the UK. Alone with the radio industry increase Britain's GDP by 1.1% a year, and the efficiency is estimated to exceeded £24 billion. The direct contribution of radio spectrum allocation to national GDP has risen to around 37 billion, or 3% of GDP [14].

Using above methods, the direct economic impact of radio spectrum resources has also been measured in Denmark, and its conclusions are similar to those economic value and impact of spectrum resources in UK [15].

Both methods can estimate the economy contribution of radio spectrum allocation in a country, but are based on different assumptions for treatment of the wider economic displacement. GDP and employment do not take account of the wider economic displacement, and the method of consumer and producer surplus take full account of wider economic displacement. While the disadvantage of the consumer and producer surplus method is that the demand curve can be difficult and time consuming to determine [9].

In addition, other literatures on relationship between optimization allocation of radio spectrum resource and economic include: Seok *et al.* considered alternatives of spectrum resource allocation in technology innovation [16]. Mazar proposed government regulation and management mode of radio spectrum resource allocation [17]. The research on the economic value of radio spectrum resources is mainly based on the utility axiology, so the different point of view for spectrum utility and value embodiment also formed [18]. Youssef *et al.* believed that its influence can be reflected by the contribution of spectrum resources to relevant application industries [19], and Gang *et al.* argued that the economic impact through the market value of spectrum resource application services and interference rights [20]. Menezes proposed that radio spectrum auction and bidding based on triangle distribution [21], and Lawrence explored the economic value and influence of radio spectrum resources in spectrum auction [22]. Pieter et al. suggested index system of economic impact assessment of radio spectrum resources, and apply AHP to determine the weight of the influencing factor [23]. Paul et al. considered total social contribution, input cost, economic growth potential in radio spectrum resource application enterprises [24]. And Sun Jing's research on the influence of radio spectrum resources on economic growth from the perspective of economic value [25].

All these measurement methods and indexes for economic influence of spectrum resources, focus on the analysis of the direct impact or contribution of radio spectrum resource allocation to the economy mainly. But the indirect influence of radio spectrum resources is not considered as an important carrier of ICT application on various industries in social development, as well as the comprehensive contribution rate to the overall economic operation. On the other hand, the index system or evaluation method for social economy influence of spectrum resource allocation is adopted relatively single, which cannot be combined with the rapidly developing factors such as artificial intelligence, industrial interconnection and intelligent transportation closely, and the information maturity which associated with these developing factors has not analyzed and researched fully.

Therefore, radio spectrum resources are regarded as production factor other than capital and labor in this paper. Through the important carrier role of industries, such as communication equipment manufacturing and mobile communication industries, which rely on the allocation of spectrum resources, and the classification and analysis of information maturity indicators, the indirect impact and comprehensive contribution of optimal allocation for spectrum resources to economic growth are obtained. Accordingly, it promotes the effective use of key communication information technologies, improves the efficiency of resource allocation, and provides important data analysis and decision-making recommendations for improving the economic growth level of the intelligent era.

Combining theory of production factors for radio spectrum resources, we propose impact evaluation method of spectrum resource allocation on economic growth based on rough set - general production function. With those various assessment methods of the resources allocation and technological progress on economic growth are taken into account. The paper is organized as follows: First of all, an impact factors set of resource allocation to economic growth based on information maturity is presented, to obtain the influence of spectrum resource allocation through ICT application in various industries; Secondly, the index of key influencing factors such as mobile terminals is extracted using rough set theory, namely, the core index of production factors is obtained. Finally, the generalized production function is used to obtain the comprehensive influence and contribution of optimal allocation for radio spectrum resources to economic growth.

II. DATA INTERFACE AND THEORETICAL APPROACH

Before we describe the actual details of the impact factors set, we will discuss about some important data interface and theoretical approach which are an important element of the economic influence assess method.

A. THE SOURCE OF DATA AND INFORMATION

In the process of data collection and processing, economic data of information industry (including communication equipment manufacturing and mobile communication) or intelligent industry is collected in ‘‘electronic information industry bulletin(2007-2017)’’ in the Ministry of Industry and Information Technology, ‘‘Intelligent manufacturing development plan (2016-2020)’’, ‘‘China Internet network development statistics report (2017) ’’ of the China Internet network information center (CNNIC) and other reports respectively. According to the characteristics for physical properties of natural resources, the optimal allocation unit of radio spectrum resources is measured in ‘‘MHz’’. And the key data, such as mobile user terminals, come from the statistical annual report of provincial communications administration and research reports of ‘‘wind’’ or ‘‘choice’’ consulting agencies.

Consistent with the traditional production function data processing method, data of China’s economic growth from 2006 to 2017 is selected. Meanwhile, all production factors are represented by stock data. Then, GDP, fixed asset investment and annual average number of employees are introduced to represent economic growth, capital stock and labor force variables. Where, the GDP index is calculated according to the actual GDP (last year = 100). At the same time, the inflation factor is deducted by means of mitigation, choose base period and eliminate inflation effect namely, and the fixed asset investment is calculated by the perpetual inventory method. The all data are collected from ‘‘China statistical yearbook (2006-2017)’’and other materials provided by the National Bureau of Statistics.

B. ANALYSIS OF INFLUENCING FACTORS

Take into account that the production function method will be adopted in the future to estimate the economic impact of optimal allocation for radio spectrum resources, combined with the recent research results on optimal allocation of radio spectrum resources, the indicator system of resource optimization allocation and economic influencing factors is provided based on information maturity, shown as in table 1.

Among them, ITU information Index IDI (ICT Development Index) is the abbreviation of the information and communication technology development index published by ITU, which reflects a composite index set composed of 11 elements of information development level comprehensively, involving information infrastructure, information use, knowledge level, development environment and effect, information consumption and so on. And the information development index (IDI), is published by research institute of the National Statistics Bureau, electronic information industry development institute and other authoritative agency, including 5 sub-indexes and 10 specific indicators.

Refer to ‘‘the white paper on assessment of industrial internet maturity (version 1.0)’’, issued by Alliance of Industrial Internet (AII), the connectivity elements of index system in evaluation model, include those construction level of network, information and security infrastructure mainly, which associated with the networking capacity of machine tools, process devices, industrial robots, sensor equipment, intelligent production lines and other production factors and so on.

According to ‘‘construction guidelines for national vehicular networking industry standard system (information and communication)’’ issued by the ministry of industry and information technology of China, and the content of ‘‘communication services and application technical standards’’, the relevant impact indexes of intelligent transportation and vehicular networking are provided.

C. IDENTIFICATION OF KEY PRODUCTION FACTORS

In this paper, generalized Cobb-Douglas production function is used to measure the comprehensive influence of spectrum resources on economic growth. The method obtains the potential output level by substituting the actual capital stock, estimated potential employment and total factor productivity into the production function, which advantage is to reflect the characteristics of supply side and the structural changes of factors, meanwhile to analysis factors structural of for mining its cause [26], [27]. On the other hand, the disadvantage is the high requirement of data quality, and all input factors is difficult to estimate. The production function method will be used in the comprehensive economic impact assessment of spectrum resource allocation. Due to its biggest advantage is to balance the influence of production factors and technological progress while estimating the contribution, to reflecting

TABLE 1. The impact index of resource allocation on economic growth based on information maturity.

Category		Index	Sub-index
Information maturity index	ITU Information index	ICT access	Penetration rate of fixed line
			Penetration rate of mobile telephones
			International export bandwidth per capita
			Penetration of home computer
			Penetration of internet household
		ICT application	Internet penetration rate
			Population penetration rate of fixed broadband
			Population penetration rate of mobile broadband
		ICT skills	Average years of education
			The gross enrollment ratio of secondary school education
			The gross enrollment ratio of higher education
	Information development index	Infrastructure	Owning rate of television
			Owning rate of fixed line
			Owning rate of mobile telephones
			Owning rate of computer
		Application index	Internet users per 100 people
		Knowledge education index	Education index(literacy rate, enrollment rate, education years)
		Environment and effects	The value added of information industry accounted for the proportion of GDP
			Research and development of the information industry accounted for the proportion of GDP
			Per capita GDP
		Information consumption	Information consumption coefficient
	Intelligent development index	Intelligent manufacturing and industrial Internet	Smart device networking
			Information network facilities
			Production resource connection
		Intelligent transportation and Internet of vehicles	Information communication platform application
			Information sharing and use
			Basic data and cloud services
			Travel, safety and rescue applications

the overall situation of economic growth, and recognized by the academic community widely.

In view of the generalized Cobb-Douglas production function requires regression analysis of production factors, the key production factors of evaluation index should be extracted, by sorting the impact index of resource allocation on economic growth based on information maturity. Allow for rough set theory is a useful tool for dealing with uncertainty and ambiguity, which proposes a data inference method from the knowledge classification perspective. Therefore, it is suitable to solve the problem of screening various complex factors. The main approach is to use the method of knowledge reduction to derive decision making or classification rules on the basis of keeping the overall classification ability unchanged [28], [29]. Starting from the description of a given problem, the inner law of the problem can be obtained through the approximation domain of the indistinguishable relation of a given problem. Meanwhile the defect can be overcome that the traditional methods of processing uncertain information often need prior knowledge or additional data. Rough set theory is used to sort the influential indicators to obtain the key production function indicators in this paper. The key index represents the important information in the original index system, which can provide a good data basis for the subsequent operation of the production function. The basic principle of rough sets is shown as follows:

Definition 1: A quad $S = (U, A, V, f)$ is an information system, of which $U \neq \phi$ is known as domain; A represents a Non-empty finite set of all attributes, using $V = \bigcup_{a \in A} V_a$; V_a is range of attribute a; f represents an information function of $U \times A \rightarrow V$, which assigns an information value to each attribute of each object.

Definition 2: A binary equivalence relation $IND(B)$ is determined by each attribute subset $B \subseteq A$:

$$IND(B) = \{(x, y) \subset U \times U | \forall a \in A, f(x, a) = f(y, a)\}$$

Definition 3: Equivalence relation $IND(B)$ constitutes a division of U, while $B \subseteq A$, expressed by $U/IND(B) = \{X_1, X_2, \ldots, X_n\}$. Where, X_i represent different equivalence classes, which form an equivalence class with all indistinguishable objects in case of $IND(B)$, denoted as $[x]_{IND(B)}$.

Definition 4: If $a \in A$, and $IND(B) \neq IND(A - \{a\})$, a is necessary in A; otherwise a is redundant.

Definition 5: $H(P)$ is the information entropy of attribute subset $P \subseteq A$, obtained by the following function:

$$H(P) = -\sum_{i=1}^{m} P(X_i) InP(X_i) \tag{1}$$

In the above equation, $U/IND(P) = \{X_1, X_2, \ldots, X_m\}$ and $P(X_i) = \frac{|X_i|}{|U|}, i = 1, 2, \cdots m$.

Definition 6: $S_A(a)$ is used to express the important of attribute which in $a \in A$, given as follows:

$$S_A(\mathrm{a}) = |H(A) - H(A - \{\mathrm{a}\})| \quad (2)$$

If $S_A(a) > 0$, then $a \in A$ is necessary in A. If $S_A(a) = 0$, then a is redundant.

Based on the rough set theory, the selection algorithm of key influencing factors is expressed as follows specifically:

Step 1: $H(A)$ and $H(A - \{\mathrm{a}\})$ can be calculated using equation (1), which are information entropy of attribute set A, which is the collection of all primary indicators in the index system.

Step 2: $S_A(a_i)(i = 1, 2, \cdots n)$ can be calculated using equation (2). While, indicators are deleted when $S_A(a) = 0$, remained with $S_A(a) > 0$, which recorded as $B = \{b_1, b_2, \ldots b_s\}(s \leq n)$ at same time;

Step 3: $S_B(b_j)(b_j \in B)$, importance degree of each indicator in the indicator set B, can be calculated then;

Step 4: Finally, the correlation of each index in indicator set B is calculated. According to the importance of each index, the index with lesser relative importance can be removed, and the index system $C = \{C_1, C_2, \cdots C_t\} (t \leq s \leq n)$ can be obtained. Then the most important is selected as the key factor index.

D. THE ANALYSIS METHOD OF RESOURCE ALLOCATION - ECONOMIC IMPACT

In the production function method, those factors, such as actual capital stock, estimates of potential employment, total factor productivity (TFP) and so on, are substitute into the production function to obtain the potential output level. Particularly the advantage is that the economic characteristics of the supplier can be reflected, and the abnormal changes in the structure of the element can also be showed accurately. Furthermore structural analysis to factors can be carry on, and the reason of changes can be displayed. However, its disadvantage lies in the high demand on the quality of factor data, and it is more difficult to estimate each input factor. So the production function method will be used to estimate the impact and contribution of spectrum resource allocation to GDP. Considering that its greatest advantage lies in the ability to estimate the contribution rate while the impact of production factors and technological progress is taken into account, and the overall situation of economic growth can be reflected, which is widely recognized by the academic circle.

According to the general principle and theoretical analysis of Cobb-Douglas production function, the following hypothesis is implemented:

1) Hypothesis 1: Spectrum resource is the independent production factor with labor, capital and technological progress.

2) Hypothesis 2: The change of each factor input is unidirectional according to their average change rate. Alone with the spectrum resource factor is introduced, and the Cobb-Douglas production function can be written as:

$$Y = A \times e^{\mu t} \times L^{\alpha} \times K^{\beta} \times I^{\gamma} \quad (3)$$

Then logarithm operation is taken in both sides of equation(3), and wrote as:

$$InY = InA + \mu t + \alpha InL + \beta InK + \gamma InI \quad (4)$$

where Y is GDP, A denotes comprehensive factor productivity (constant), e represent the base of the natural logarithm. And μ is the rate of technological progress, t denotes time (in 2006, $t = 1$; 2007, $t = 2$; …2017, $t = 12$). Other variables L, K and I, denote the number of labor inputs, production capital and spectrum resource separately. At the same time, the parameters α, β and γ, represent the elasticity coefficient of labor force output, capital output, and spectrum resource output respectively.

According to the derived conclusion of the traditional Cobb-Douglas production function, the influence equation of spectrum resource factors on GDP growth can be received:

$$C = \frac{\gamma \times \frac{1}{I_{\text{report period}}} \times \frac{I_{\text{report period}} - I_{\text{base period}}}{N}}{\frac{Y_{\text{report period}} - Y_{\text{base period}}}{N} \times \frac{1}{Y_{\text{report period}}}} \quad (5)$$

where C is the influence degree of spectrum resource factor on economic growth, and N is number of years between the report period and the base period. And the definition of other symbols is consistent with the previous description. In the same way, the impact and contribution of capital or labor on the economy can be calculated. Meanwhile, except for the influence of three input factors, the remaining is the contribution of scientific and technological progress.

III. DATA ANALYSIS AND RESEARCH RESULTS

A. DIRECT IMPACT OF RESOURCE ALLOCATION ON ECONOMY

Considering the spectrum resources is closely related to the information maturity, spectrum resources allocation quantity of the mobile telecommunication industry (in 2006-2017) is adopted in this paper mainly. And the Other economic data is collected from China statistical yearbook (in 2006-2017). Then the detailed data description is shown in table 2 as below.

Using software "Eviews 8.0", the economic impact of main spectrum resources allocation is calculated and the regression results could be obtained. From the analysis of the results, the direct impact of spectrum resource allocation on economic growth is not significant statistically, with coefficient LNI was 0.0183. On other words, the regression calculation of the direct economic impact of the main spectrum allocation amount does not reflect its contribution at the present stage.

After examining the causal relationship of relevant factors, the results were obtained in figure 1 as below:

TABLE 2. Relevant data of optimal allocation for radio spectrum resource on economic impact.

index /year	GDP(billion)			Number of employees (ten thousand)	Fixed investment (billion)	Main allocation of spectrum resources (MHz)
	Nominal GDP	Deflator	Real GDP			
2006	219438.5	101.5	216195.5	74978	109998.2	140
2007	270232.3	104.8	266291.2	75321	137323.9	140
2008	319515.5	105.9	301714.4	75564	172828.4	140
2009	349081.4	99.3	351542.2	75828	224598.8	235
2010	413030.3	103.3	399835.4	76105	251683.8	235
2011	489300.6	105.4	464232.1	76420	311485.1	235
2012	540367.4	102.6	526673.9	76704	374694.7	235
2013	595244.4	102.6	580160.2	76977	446294.1	455
2014	643974.0	102.0	631347.1	77253	512020.7	455
2015	689052.1	101.4	679538.6	77451	561999.8	455
2016	219438.5	101.5	216195.5	77603	606465.7	455
2017	270232.3	104.8	266291.2	74978	109998.2	455

Pairwise Granger Causality Tests
Date: 03/15/18 Time: 11:50
Sample: 2005 2016
Lags: 1

Null Hypothesis:	Obs	F-Statistic	Prob.
LNI does not Granger Cause LNY	11	0.84525	0.3848
LNY does not Granger Cause LNI		8.73330	0.0183

FIGURE 1. The causal relationship of optimal allocation of spectrum resources on economy.

From the test results of causal relationship above, it is also known that the increase of spectrum resource allocation is not the direct cause of economic growth, with the causal relationship is 8.733. But economic growth is the reason for the increase of spectrum resources, with the statistical data was 0.845. That is to say, economic growth leads to an increase in the demand for optimal allocation of radio spectrum resources.

B. IDENTIFICATION IN THE KEY INDEX OF PRODUCTION FACTOR

Firstly, the impact index of resource allocation on economic growth based on information maturity is reduced. In the impact index system, 27 sub-indexes are involved in 10 indexes. While the similarity sub-index is reduced, for example, "Fixed telephone penetration rate" and "fixed telephone ownership rate", "Mobile phone penetration" and "mobile phone ownership" and so on. Then the impact index system is simplified from 27 sub-indexes to 22 sub- indexes.

Secondly, the rough set theory is used to screen the key production factor index in the influence factor system based on information maturity, in order to describe the impact of optimal allocation for spectrum resources on economic growth quantitatively. Using equations (1) and (2), the importance of each index could be calculated.

For discussing importance of each index, the definitions are given as below:

A quad $S = (U, A, V, f)$ is defined as a decision system in the key index identification for production factor. Where, $E \neq \phi$ is domain, and A is a nonempty finite set for decision attributes identification. In a general way, $A = C \cup D$, $C \cap D = \phi$, where C is called a conditional attribute, and D is decision attribute.

Considering the limited length of the paper, 31 groups of regional data are selected through investigation. The east region include: Beijin, Tianjing, Hebei, Liaoning, Shanghai, Jiangshu, Zejiang, Fujian, Shandong, Guangdong, Hainan. And the middle region include: Shanxi, Jilin, Heilongjiang, Anhui, Hunan, Jiangxi, Henan, Hubei. At last, the west region, which include: Guangxi, Chongqing, Guizhou, Yunnan, Xizhang, Gansu, Qinghai, Shanxi, Sichuan, Neimenggu, Ningxia, Xinjiang and so on. All the regional data can be expressed using $E_1, E_2, E_3 \cdots E_{31}$ separately.

Through investigating and researching, relevant data of the original sample is obtained shown in table 3 as below:

Step1: The importance degree of decision attribute for each production factor is determined. In the fields of information and communication, intelligent manufacturing, intelligent transportation, smart city, and so on, 10 experts with relevant technical or economic expertise and practical experience shall be selected. Those evaluation values proposed by experts are summed and averaged in order to assess the importance of production factors $(C_1, C_2, C_3 \cdots C_{22})$. And the importance degree of decision attributes for each production factor is

TABLE 3. **Relevant data of the original sample (by the year 2017).**

index \ region	Bei jin	Tian jing	He bei	Liao ning	Shang hai	Jiang shu	Ze jiang	Fu jian	Shan dong	Guang dong	…	Ning xia	Xin jiang
Penetration rate of fixed line（%）	32	20	11	20	30	21	23	21	10	24	…	10	20
Penetration rate of mobile telephones（%）	178	96	95	101	130	102	129	107	96	130	…	106	89
Broadband access fixed internet(Per 10,000 households)	541	339	1910	1058	681	3106	2464	1373	2588	3246	…	159	569
Broadband access mobile internet(Per 10,000 households)	4639	1309	6211	3936	3393	9257	7456	3508	8507	14160	…	682	1855
Penetration rate of internet household（%）	78	65	53	63	74	57	66	70	53	74	…	51	55
Penetration rate of home computer（%）	66	33	19	28	50	21	22	18	19	32	…	28	25
Average years of education（years）	11	10	8	8	11	9	8	9	9	9		8	8
The gross enrollment ratio of secondary school education(Per 100,000)	2557	3508	5938	4530	2830	4762	5303	5795	6043	6550	…	7601	7357
The gross enrollment ratio of higher education(Per 100,000)	5028	4058	2192	2845	3327	2937	2355	2438	2620	2431	…	2225	1780
Owning rate of television（%）	110	97	36	56	97	85	93	69	61	89	…	50	30
…	…	…	…	…	…	…	…	…	…	…	…	…	…

TABLE 4. **The decision attribute of identification for key production factors.**

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	…	C_{22}	D
E_1	3	3	1	2	3	2	2	1	3	3	3	2	1	…	2	3
E_2	2	1	2	1	2	1	1	2	2	1	1	1	1	…	3	2
E_3	1	1	1	2	1	2	1	1	2	1	2	2	3	…	2	1
E_4	2	1	2	2	2	2	3	1	2	2	1	2	1	…	1	1
E_5	3	2	1	2	3	2	2	1	3	3	3	2	1	…	2	3
E_6	2	1	1	2	2	1	1	2	2	1	1	2	1	…	2	2
E_7	2	2	2	1	2	1	1	1	1	1	1	2	1	…	1	3
E_8	2	1	1	2	1	2	1	1	2	1	2	2	3	…	2	2
E_9	1	1	1	2	1	2	1	2	2	1	2	2	3	…	2	1
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
E_{31}	2	1	3	2	2	1	1	2	3	1	3	2	1	…	2	1

divided into extremely important, quite important and moderate importance, with denoted as $D = (D_1, D_2, D_3)$. Where, $D_1 = 3, D_2 = 2, D_3 = 1$.

Step2: All conditional attribute values are discretized. According to certain discrete rules, the conditional attribute values are converted into graded values, which are classified into three levels, each corresponding to a value 3, 2, 1. In turn, the conditional attribute values of $C_1, C_2, C_3 \cdots C_{22}$ and the decision attribute values of D are obtained, as shown in table 4.

Step3: Dependence degree is determined. Base on the table 4, the dependence of decision attribute D to condition attribute C can is defined, represented by $\gamma C_i(D)$. There is dependence between D and C, and the dependency indicates the proportion of equivalence instance to all instances in the decision system, which can be correctly divided into equivalence classes about C, using information of condition attribute C. And the dependence is expressed as a coefficient $\gamma C_i(D)$:

$$\gamma C_i(D) = \frac{card(posC_i(D))}{card(E)} \tag{6}$$

where, the cardinality of set is represented by $card(\cdot)$.

Step4: The importance degree of attribute C is solved. The importance degree of conditional attribute $C_i (C_i \in C)$ can be understood as the matching degree of change in decision making, removing attribute C_i from the conditional attributes. The greater the change, the more important the attribute is. The calculation equation for importance degree of the attribute C is:

$$Sig(C_i) = \gamma C(D) - \gamma (C - C_i)(D) \tag{7}$$

Step5: Importance degree is normalized. The importance factor is obtained by normalizing the importance degree of

TABLE 5. The importance degree of conditional attribute in identification for key production factors.

conditional attribute	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
importance degree	---	0.097	---	0.032	0.032	---	---	0.032	---	---	---
conditional attribute	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}
importance degree	0.065	---	---	---	0.065	0.032	0.032	---	---	---	---

TABLE 6. Comprehensive impact of optimal allocation for spectrum resources on economic growth.

year	Y (Constant price in 2005)	L	Investment	K (Constant price in 2005)	Tel	lnY	lnK	lnTel	c
2008	351542.2	74978	109998.2	628785.01	72596	10.64	2.39	11.19	——
2009	399835.4	75321	137323.9	692837.85	84196.3	10.77	2.56	11.34	0.46
2010	464232.1	75564	172828.4	764031.13	97569.8	10.88	2.69	11.49	0.39
2011	526673.9	75828	224598.8	826998.76	111023	10.95	2.79	11.62	0.41
2012	580160.2	76105	251683.8	987142.49	123376.9	11.02	2.95	11.72	0.43
2013	631347.1	76420	311485.1	1125792.94	129135.2	11.08	3.11	11.77	0.22
2014	679538.6	76704	374694.7	1253174.09	131080	11.13	3.25	11.78	0.08
2015	729005.4	76977	446294.1	1472195.43	132780	11.18	3.39	11.80	0.07
2016	810903.8	77253	512020.7	1728917.99	142132	11.27	3.52	11.86	0.26
average									0.29

Note: Because of the one-year lag in the Yearbook statistics, all the data in the table have been advanced correspondingly for one year.

attributes. ω_i is the importance degree of the ith condition attribute, show as below:

$$\omega_i = \frac{Sig(C_i)}{\sum_{i=1}^{n} Sig(C_i)} \tag{8}$$

Step6: Operation results can be awarded using equation (6-8), which include:

$$card(E) = 31, \quad card(posC(D)) = 31,$$
$$\gamma C(D) = \frac{card(posC(D))}{card(E)} = \frac{31}{31} = 1;$$

And the importance degree of each attribute is shown in table 5:

From Table 5, the mobile user terminal C_2 is the most important index in the evaluation index system based on information maturity through calculation. Therefore, C_2 is selected as the key factor index of the impact for spectrum resources on the economy.

C. DATA ANALYSIS OF COMPREHENSIVE IMPACT FOR RESOURCE ALLOCATION ON ECONOMIC GROWTH

Using the software Eviews 8.0 again for corresponding operations, the regression results showed that: the regression coefficient LNTEL is 0.6485, which is significant at 1% level. On condition that the allocation number of spectrum resource is represented by the number of mobile user terminals. Therefore, it is possible to calculate the comprehensive impact of optimal allocation for radio spectrum resources on economic growth, with the mobile user terminals as carriers. So number of mobile user terminals is used for the regression calculation of the comprehensive impact and contribution on economic growth, those specific data are shown in Table 6.

According to Table 6, the comprehensive impact and contributes on economic growth came from optimal allocation of radio spectrum resources based on information maturity is concluded to be 29% approximately. With the mobile user terminal is regarded as an important production factor in index system of ITU information, information development and intellectualization development, through its important carrier function.

IV. CONCLUSION AND FUTURE WORK

Radio spectrum resources, as well as land and mineral resources, are the scarce natural resources, which play an important role in the rapid and stable development of national economy and society. Especially as an important economic factor, spectrum resources are put into industrial production and economic activities, which have great economic value and great influence on economic growth. Based on the needs of the new generation in ICT to support the rapid economic and social development, this paper analyzes and studies the comprehensive impact and contribution of optimal allocation for radio spectrum resources on economic growth.

Firstly, the data of radio spectrum resources in the economic growth process are clarified, and the interface of optimal allocation for radio spectrum resources in related industries is defined. Then the basic data of radio spectrum resources, optimal allocation data, information industry data, intelligent industry data and economic data are analyzed respectively. The index system of resource allocation on economic impact factors based on information maturity is constructed. Thus, a theoretical prerequisite is provided, for the economic impact analysis of radio spectrum as a public resource.

Secondly, the generalized Cobb-Douglas production function is used to analyze the economic impact of spectrum resource allocation, and a conclusion is obtained that the increase of spectrum resource allocation has not been the cause of direct economic growth. While the economic growth is the reason for the increase of spectrum resources, that is, economic growth leads to the increase of demand for optimal allocation of radio spectrum resources.

Finally, the influence and contribution of radio spectrum resources on the economy growth are evaluated based on the rough set theory. Using the number of mobile user terminals as the key factor index, the regression calculation of the comprehensive economic impact and contribution of spectrum resources is carried out. When the regression coefficient is 0.6485, the estimated results are obtained, that is, through the important carrier role of mobile user terminals, the comprehensive impact and contribution of radio spectrum resource allocation on economic growth is 29%.

The results show that radio spectrum resources provide a solid foundation for the development of ICT. Depending on the rapid development of ICT, every industry has huge potential of economic value. With the efficiency improvement of the optimization allocation for spectrum resources and the further improvement of the market mechanism of spectrum resources, the transformation and upgrading of information industry and intelligent industry in the national economy, especially the intelligent manufacturing industry, will receive priority protection of spectrum resources. Therefore, there are many problems to improve the efficiency of radio spectrum resource allocation, give full play to its important economic influence, and encourage effective innovation in the development and application of new ICT. Because of the analysis of economic value and supporting theoretical research have a certain academic value and practical value, the optimal allocation theory of radio spectrum resources deserves further research.

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