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Sectoral Electricity Consumption and Economic Growth: The Time Difference Case of China, 2006–2015

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Abstract: Unlike existing studies focused on the causal relationship between electricity consumption and economic growth at the macro level, this paper uses monthly data from January 2006 to December 2015 and applies the correlation coefficient, as well as Kullback-Leibler (KL) divergence, to study the time difference relationship between sectoral electricity consumption and economic growth. The empirical results draw some main findings as follows: First, the time difference relationships show diversity at the sector level but will form a kind of overall characteristic between economic growth and total electricity consumption. Secondly, not all sectors have a remarkable correlation between sectoral electricity consumption and economic growth as only part of them have reasonable values to describe the time difference relationship. Thirdly, the results present both diversity and aggregation at the industry level, while lagging sectors mainly concentrate in the manufacturing industry. The relationship between sectoral electricity consumption and economic growth can be further explored and described from a new perspective based on the results. Further, the trend of economic development and sectoral electricity consumption can be predicted to help policy-makers formulate proper policies.

Keywords: sectoral electricity consumption; economic growth; China; time difference; Kullback-Leibler (KL) divergence

1. Introduction

With global economic development, more energy resources will be consumed to support higher production activity levels and living standards. As one of the major components of energy consumption, electricity plays a key role in both the fuel mix evolution and economic growth. Electricity has an ever-increasing share of primary energy consumption, which was 42% in 2015, along with a long-term trend of electrification [1]. A number of papers have studied the causal relationship between energy consumption and economic growth across different countries, and some studies focused on the relationship between electricity consumption and economic growth [2,3]. The results of these studies are not consistent but cover almost all causal possibilities, which, generally speaking, can be classified into four categories (unidirectional causality from electricity consumption to economic growth, unidirectional causality from economic growth to electricity consumption, bidirectional causality between economic growth and electricity consumption, and no causal link between economic growth and electricity consumption) [4–8].

China has achieved rapid economic growth over the past few decades and has become the world's second largest economy. During this time China overtook the United States as the largest electricity consuming country in the world in 2011. At the end of 2015, the total electricity consumption of China was 5550 TWH with the installed generation capacity of more than 1506 GW. Considering the critical role electricity consumption played in the process of industrialization and urbanization, researchers have paid some effort to study the relationship between economic growth and electricity consumption in China. Lin (2003) used a macroeconomic approach to analyze the main factors affecting electricity demand in China based on the data of 1978–2001 and concluded that economic growth is the unidirectional Granger cause of electricity consumption [9]. With the data of 1971–2000, Shiu and Lam (2004) applied the error-correction model to examine the causal relationship between the real GDP and electricity consumption [10]. The estimation results indicated that there is unidirectional Granger causality running from electricity consumption to economic growth, which is the opposite to the conclusion Lin (2003) obtained. Yuan et al. (2007) applied co-integration theory to analyze the data of 1978–2004 and reached the same conclusion that there is only unidirectional Granger causality running from electricity consumption to economic growth, but not the vice versa [11]. Furthermore the estimation results with series data implied that the Granger causality is probably related with the business cycle. Though related studies have indicated that, in China, the relationship between economic growth and electricity consumption is relatively stable and positively correlative, there still exist some deviations during special periods, such as the Asian financial crisis and the global economic crisis. Selecting the monthly data from January 2007 to December 2014, Lin and Liu used the structural vector autoregressive model to explore the reason for the large deviation during these periods of economic crises [12]. According to the conclusions, during the economic crisis inventory investment adjustment is the main factor of the deviation, but the reason that causes the deviation is complicated and could be different in different stages. Additionally, the deviation is a short-term phenomenon and will disappear once the economy returns to stable growth. On the one hand, most existing studies focused on the causal relationship between economic growth and electricity consumption. In fact, the analysis method, such as Granger cause analysis, is generally sensitive to minor changes in model structure [11] and, hence, some research conclusions are not consistent. On the other hand, these studies usually selected highly aggregated data, although not all sectors are equally energy intensive [13]. Some special issues at the industry level could be ignored when using aggregate data at a higher level.

On the basis of the existing studies, it is worthwhile to make further efforts examining the relationship between sectoral electricity consumption and economic growth. This paper focuses on the correlation between economic growth and sectoral electricity consumption in China during the last decade. Monthly data is selected to examine the similarities and differences of the correlativities between economic growth and 46 sectors. The rest of this paper is organized as follows: Section 2 introduces the data and methodology of the study; Section 3 depicts the empirical analysis and discussion; and Section 4 presents the concluding remarks.

2. Data and Methodology

2.1. Overview of Economic Growth and Electricity Consumption

After decades of rapid development, China's economic growth rate has been declining recently. According to data released by the World Bank [14], during the past decade, 2006–2015, the average annual growth rate of GDP is 9.2%, with the highest growth rate of 14.2% in 2007 and the lowest of 6.9% in 2015, as shown in Figure 1. Industry value-added increased at an average annual growth rate of 9.7%, with the highest at 15.0% in 2007 and the lowest at 6.0% in 2015. Meanwhile, with the economic structure adjustment, the share of industry value-added in the total GDP overall continued to decline, which decreased from 47.4% in 2006 to 40.5% in 2015.

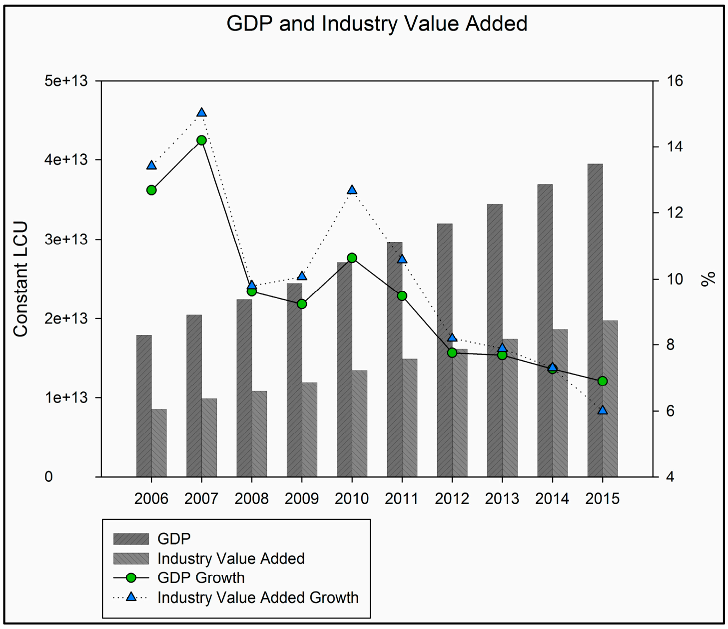

Figure 1. GDP and industry value-added in China from 2006 to 2015.

With economic development and electrification, electricity consumption in China has continued increasing with an average annual growth rate of 7.7% during the last decade, with the highest at 15.2% in 2006 and the lowest at 0.6% in 2015, as shown in Figure 2. Total electricity consumption in 2015 released by the National Energy Administration has reached 5550 TWH. At the industry level, industry-wide electricity consumption accounted for 86.9% of total electricity consumption with the corresponding proportions of 1.8% for agriculture, 72.2% for industry, and 12.9% for service, respectively.

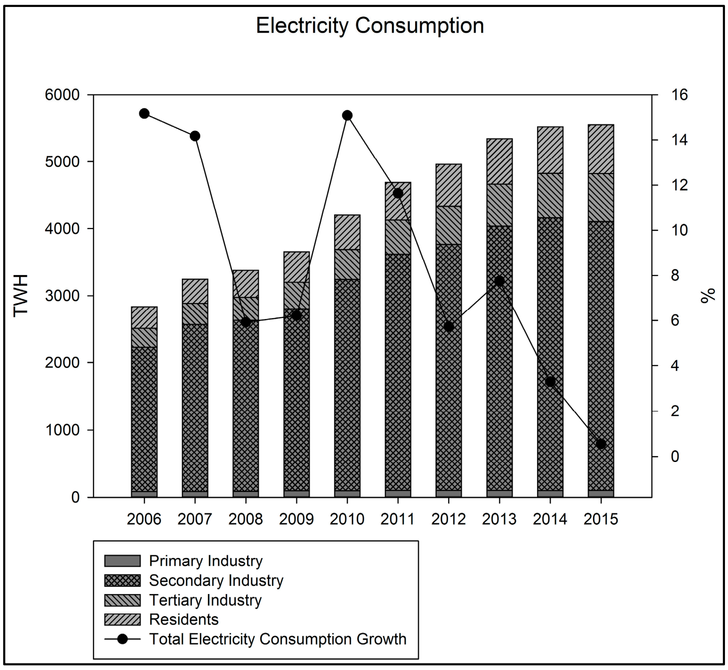

Figure 2. Electricity consumption of China from 2006 to 2015.

2.2. Data

Unlike other studies, this paper uses monthly data of economic growth and sectoral electricity consumption. Considering monthly data of GDP is not available, we chose the growth rate of industrial value-added as the proxy of economic growth. The monthly data of the growth rate of industrial value-added are obtained from the National Bureau of Statistics of China. Due to the characteristics of investigation and release, there is no data for some individual months. The interpolation method is applied to supplement the data to ensure the integrity of time series, which will bring some acceptable errors. There is more than one sector classification method, each of which has its own advantages and suitable occasion. The monthly data of sectoral electricity consumption are obtained from the China Electricity Council, thus 46 sectors were divided on the basis of the data obtained. For convenience of description, we use sector codes instead of sector names, which are given in the Appendix A. According to sectoral electricity consumption data, we can obtain the growth rate of each sector, which can be formed into time series of the same type with economic growth. All series have been seasonally adjusted by the Census X-12 method to remove the influences of predictable seasonal patterns. Due to limited data, the time interval selected in this paper is from January 2006 to December 2015, which covers the Eleventh Five-Year Plan and the Twelfth Five-Year Plan.

2.3. Time Difference Correlation Coefficient

Correlation coefficient is a statistical indicator which can reflect the degree of linear correlation between variables. For time series, correlation at different terms can be measured by the time difference correlation coefficient [15]. To calculate this coefficient between two series, we first select a certain time series as the basic series, and then calculate the correlation coefficient by changing the time relationship between them. On the condition that a series leads or lags the basic series for several terms, a series of time difference correlation coefficient can be obtained.

Assume that $y = \{y_1, y_2, \cdots, y_n\}$ is the basic series, $x = \{x_1, x_2, \cdots, x_n\}$ is another series and r is the time difference correlation coefficient. The mathematical expression of r is shown in Equation (1):

$$r_t = \frac{\sum_{i=1}^{n}(x_{i+t} - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_{i+t} - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}}, t = 0, \pm 1, \pm 2, \cdots, \quad \pm T \tag{1}$$

where t is the number of terms reflecting the time difference relationship, the positive value indicates a lag relationship and the negative value indicates a lead relationship; n is the number of data points of the series; T is the maximum number of terms.

Since the value of r_t will vary with different values of t, we can obtain a series of time difference correlation coefficient. Assuming that the number of terms corresponding to the maximum value of correlation coefficient is $t$max, then $r_{t\max}$, the maximum value of time difference correlation coefficient, can be obtained from Equation (2):

$$r_{t\max} = \max_{-T \le t \le T} r_t \tag{2}$$

Generally, the maximum value of time difference correlation coefficient is considered to reflect the time difference correlation relationship under the certain lead or lag terms whose value means the time difference length.

2.4. Kullback-Leibler Divergence

Kullback-Leibler (KL) divergence, first introduced by Solomon Kullback and Richard Leibler [16], is a measure of the difference between two probability distributions, which is also called KL divergence.

It reflects the distance between probability distributions through directed divergence. For discrete probability distributions P and Q, the KL divergence from Q to P is defined [17] as Equation (3):

$$D_{\mathrm{KL}}(P \parallel Q) = \sum_i P(i) \log \frac{P(i)}{Q(i)} \tag{3}$$

Time series is a stochastic sequence, which is a stochastic process of discretization parameter. On this account, a time series can be regarded as a probability distribution of a random variable. By standardizing the series as the sum of the sequence elements is 1, new probability distribution series can be obtained. Assume that $y = \{y_1, y_2, \cdots, y_n\}$ is the basic series, $x = \{x_1, x_2, \cdots, x_n\}$ is another series, and the elements are positive. The new series $p = \{p_1, p_2, \cdots, p_n\}$ and $q = \{q_1, q_2, \cdots, q_n\}$ after processing can be obtained from Equations (4) and (5):

$$p_j = \frac{y_j}{\sum\limits_{i=1}^{n} y_i}, j = 1, 2, \cdots, n \tag{4}$$

$$q_j = \frac{x_j}{\sum\limits_{i=1}^{n} x_i}, j = 1, 2, \cdots, n \tag{5}$$

According to Equation (3), KL divergence from q to p can be calculated by the following Equation (6):

$$k_t = \sum_{j=1}^{m} p_j \log \frac{p_j}{q_{j+t}}, t = 0, \pm 1, \cdots, \pm T \tag{6}$$

where t is the number of terms reflecting the time difference relationship, the positive value indicates a lead relationship and the negative value indicates a lag relationship; m is the number of data points of the series after data alignment; and T is the maximum number of terms.

KL divergence is always non-negative and takes the value of zero if and only if two series are equal. A smaller value of KL divergence means a more similar probability distribution. A series of KL divergence can be obtained due to changes in the value of t. Assuming that the number of terms corresponding to the minimum value of KL divergence is $t$min, then $k_{t\mathrm{min}}$ can be obtained from Equation (7):

$$k_{t\mathrm{min}} = \min_{T \leq t \leq T} k_t \tag{7}$$

The number of terms, $t$min, is considered to be the time difference length. Generally, the minimum value of KL divergence means series q is most similar to p under the certain lead or lag terms $t$min among all values in the range $[-T, T]$.

3. Results and Discussion

3.1. The Results of Time Difference Correlation Coefficient

Each value of the time difference term will have a corresponding result of the correlation coefficient, so a series of correlation coefficients can be obtained by changing the value of the time difference term. For the high-frequency monthly data, each change of one month in the length of time difference will be able to obtain a new correlation coefficient value. According to a series of findings, a shorter time difference term does not reflect the real time difference relationship because sometimes the maximum correlation coefficient appears in the longer time difference term. On the other hand, a longer time difference term does not necessarily lead to more accurate results. When changing the value of the time difference term, the whole time series data needs to be moved to meet the computational requirements. In this case, the data length of the original time series changes, which will be shorter with a larger time difference term. Further, the representativeness of the result of the time difference correlation coefficient decreases as the data length becomes shorter. Taking into account the above factors, 18 months are selected as the maximum value of the time difference term. In addition, we assume that the time difference relationship remains stable under different time difference terms with the maximum value of 18 months.

For each sector, positive and negative values of the time difference term with the maximum value of 18 months will generate 36 results of the correlation coefficient. Coupled with the result of synchronization, a total of 37 sets of results can be obtained, including the correlation coefficient and the corresponding number of time difference terms. Figure 3 shows the results of time difference correlation coefficient of all 46 sectors. Each line represents the time difference results of one sector that compares with the basic series. It reflects the correlation relationship between the electricity consumption growth of a sector and economic growth under different leading or lagging months. In Figure 3, the *t*-axis represents the number of time difference terms, ranging from −18 to 18. Negative values represent a leading relationship, while positive values represent a lagging relationship, with zero for a synchronization relationship. The r-axis represents the value of the correlation coefficient, whose maximum absolute value is not greater than 1. A positive value indicates a positive correlation between sectoral electricity consumption growth and economic growth, and a value closer to 1 indicates a higher correlation between the two series. In contrast, a negative value shows a negative correlation between sectoral electricity consumption growth and economic growth. A value of 1 means that the two series are identical, a value of −1 indicates the two series are exactly the opposite, and a value of 0 indicates that the two sequences are completely unrelated.

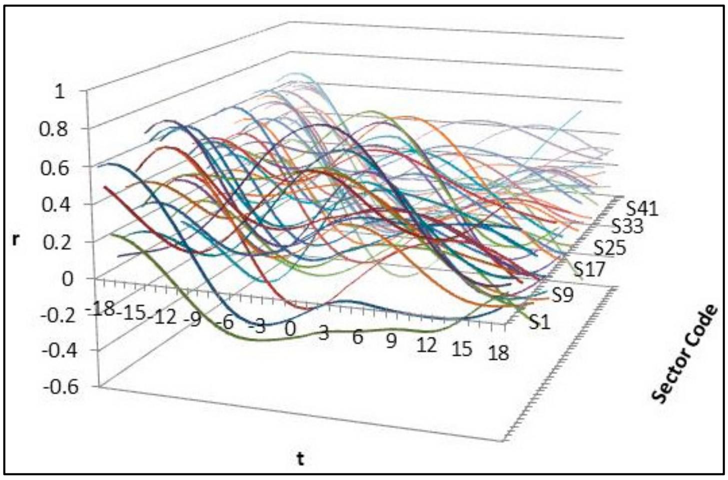

Figure 3. Correlation coefficient results of 46 sectors.

For each sector, there are 37 correlation coefficients between electricity consumption growth and economic growth. Since the maximum value of the correlation coefficient is considered to reflect the correlation relationship under the certain terms, a set of data reflecting the time difference relationship can be obtained including the largest correlation coefficient and the corresponding time difference term. Thus, the results of the time difference correlation coefficient between electricity consumption growth of all 46 sectors and economic growth can be obtained, as shown in Table 1. The correlation coefficient varies from a minimum of 0.096 to a maximum of 0.865, with all values positive, indicating a strong or weak positive correlation between the electricity consumption growth of all sectors and economic growth. S4, the sector of mining and processing of ferrous metal ores, has the maximum correlation coefficient with the time difference relationship lagging two months. S27, the sector of comprehensive use of waste resources, has the minimum correlation coefficient with the time difference relationship lagging seven months. The correlation coefficient close to zero indicates a very weak correlation between electricity consumption growth of S27 and economic growth.

Table 1. The maximum value of correlation coefficient and corresponding term.

Sector Code	$r_{t\,\max}$	t max	Sector Code	$r_{t\,\max}$	t max
S1	0.619918	−17	S24	0.691304	3
S2	0.655097	2	S25	0.665386	−16
S3	0.207185	−18	S26	0.496563	−15
S4	0.864681	2	S27	0.095785	7
S5	0.732871	3	S28	0.460174	−1
S6	0.594579	1	S29	0.505293	−1
S7	0.378078	16	S30	0.536092	−16
S8	0.630699	−15	S31	0.533781	−15
S9	0.575556	0	S32	0.386190	5
S10	0.749904	−16	S33	0.286228	−15
S11	0.702440	−15	S34	0.605046	−15
S12	0.576845	−17	S35	0.661358	−17
S13	0.687926	−15	S36	0.617100	−16
S14	0.395387	−16	S37	0.468803	−15
S15	0.239763	−15	S38	0.550531	−16
S16	0.468987	1	S39	0.303782	−15
S17	0.396814	1	S40	0.607474	−17
S18	0.354165	−2	S41	0.714993	−16
S19	0.529657	−15	S42	0.492442	−15
S20	0.539018	1	S43	0.640670	−16
S21	0.745179	0	S44	0.586767	−16
S22	0.672347	1	S45	0.390882	−16
S23	0.509891	4	S46	0.582477	−17

3.2. The Results of Kullback-Leibler Divergence

The same as the correlation coefficient results, each value of the time difference term will have a corresponding result of KL divergence. For the same monthly data, a series of correlation coefficients can be obtained by changing the value of the time difference term. For comparison and consistency analysis, 18 months are still selected as the maximum value of the time difference term.

For each sector, 36 results of KL divergence will be obtained with both positive and negative values of the time difference term. Coupled with the result of synchronization, a total of 37 sets of results can be obtained, including the KL divergence and the corresponding number of time difference terms. Figure 4 shows the results of KL divergence of all 46 sectors. Each line represents the KL divergence results of one sector reflecting the approximate degree of probability distribution between the electricity consumption growth of a sector and economic growth under different leading or lagging months. In Figure 4, the t-axis represents the number of time difference terms, ranging from −18 to 18. Negative values represent a leading relationship, while positive values represent a lagging relationship, and zero for a synchronization relationship. The value of the *k*-axis, which represents KL divergence, is always non-negative and takes the value of zero if and only if two series are equal. According to the definition of KL divergence, a smaller value means two series are more similar. A value closer to 0 indicates that the probability distribution of sectoral electricity consumption growth is more similar to the probability distribution of economic growth. When the KL divergence between two series takes the value of 0, they are completely consistent in terms of the probability distribution.

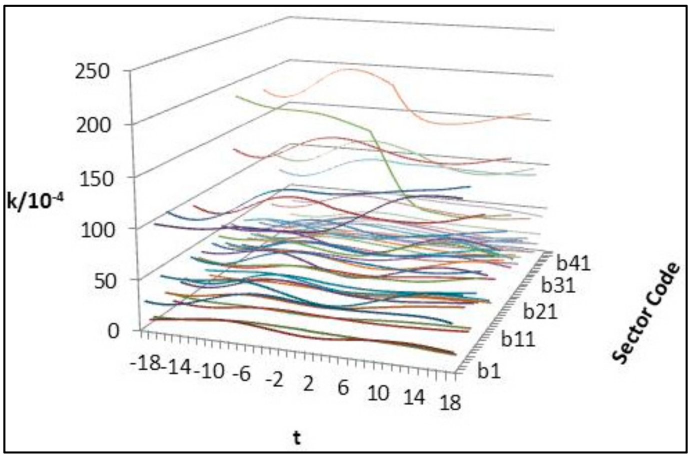

Figure 4. Kullback-Leibler (KL) divergence results of 46 Sectors.

A total of 37 results of KL divergence can be obtained for each sector. Since the minimum value of KL divergence is considered to reflect the similarity degree under the certain terms, a set of data including the minimum KL divergence and the corresponding time difference term can be selected to reflect the similarity relationship. Thus, the results of KL divergence between electricity consumption growth of all 46 sectors and economic growth can be obtained, as shown in Table 2. Since the calculated values of KL divergence were too small, the data given in the table were the results expanded by 10,000 times. The KL divergence varies from a minimum of 6.355 to a maximum of 156.639, indicating different degrees of similarity between the electricity consumption growth of all sectors and economic growth. S40, the sector of real estate, has the minimum KL divergence with the time difference relationship leading seventeen months. S36, the sector of software and information technology services, has the maximum KL divergence with the time difference relationship lagging seven months. The larger KL divergence of S36 indicates relatively weak consistency between sectoral electricity consumption growth and economic growth.

Table 2. The minimum value of Kullback-Leibler (KL) divergence and corresponding term.

Sector Code	$k_{t\,\min}/10^{-4}$	t min	Sector Code	$k_{t\,\min}/10^{-4}$	t min
S1	27.71167	−16	S24	20.67549	2
S2	7.623408	−18	S25	46.47400	−15
S3	7.278065	−18	S26	124.3153	−15
S4	97.13727	−15	S27	77.32223	12
S5	33.68715	3	S28	17.91015	-2
S6	23.21253	−16	S29	38.613873	−2
S7	98.30090	−15	S30	21.47906	−16
S8	7.389054	−15	S31	22.70924	−15
S9	8.951009	−1	S32	13.63726	5
S10	21.43661	−15	S33	17.46805	7
S11	22.61097	−15	S34	29.40884	−15
S12	19.61467	−16	S35	20.22658	−16
S13	38.41342	−15	S36	156.6389	7
S14	88.62966	−15	S37	25.48749	−15
S15	33.19246	−14	S38	42.83827	−16
S16	31.97642	2	S39	95.73843	−15
S17	12.39940	1	S40	6.354810	−17
S18	9.585951	−2	S41	74.42718	−15
S19	38.77458	−15	S42	6.529724	−15
S20	16.75553	−16	S43	9.093979	−16
S21	40.93368	−1	S44	9.476812	−16
S22	41.93267	0	S45	16.23777	−16
S23	31.39511	−15	S46	31.09458	−17

3.3. The Results of Time Difference Relationship

For each sector, both correlation coefficient and KL divergence will change with different time difference terms so that a series of data can be obtained. As can be seen from the figures, the results change continuously with at least one maximum and one minimum value, which makes the maximum of the correlation coefficient and the minimum value of KL divergence be selected out easily. The change in the results also indicates that there is a different correlation between sectoral electricity consumption growth and economic growth under different time difference terms. According to the definition of correlation coefficient and KL divergence, the maximum value in the series data of correlation coefficient and the minimum value of KL divergence are selected as the parameters reflecting the time difference relationship, as shown in Tables 1 and 2. The maximum value of the correlation coefficient is 0.865, lagging two months, and the minimum is 0.096, lagging seven months. The longest time difference term of a leading relationship is eighteen months and the longest lagging term is also eighteen months. Obviously, different sectors have unequal maximum correlation coefficients and the corresponding time difference terms are not the same. The maximum value of KL divergence is 156.639, lagging seven months, and the minimum is 6.355, leading seventeen months. The longest time difference term of a leading relationship is seventeen months and the longest lagging term is eighteen months. As with the correlation coefficient, the value of KL divergence is different in different sectors and the corresponding time difference term is also not the same. Whether for the correlation coefficient or for the KL divergence, sectors with electricity consumption growth leading economic growth account for the majority of 46 sectors.

From the numerical results, the time difference relationship of all sectors can be divided into leading, lagging, and synchronization, corresponding to the negative, positive, and zero value of the time difference term. The correlation coefficient and KL divergence reflect the time difference relationship between sectoral electricity consumption growth and economic growth from a certain aspect. The correlation coefficient reflects the interrelation and its correlation direction between two series, while the KL divergence reflects the proximity of the distribution between two series. Only when the correlation coefficient reaches the maximum value and the KL divergence reaches the minimum value at the same time, is the time difference term considered to be the real time difference relationship between the sectoral electricity consumption growth and economic growth in this study. As can be seen from the results given above, the time difference term of the maximum correlation coefficient is not always the same as that of the minimum KL divergence in each sector. The differences in correlation coefficients and KL divergences for some sectors are not significant, so it is necessary to analyze which time difference term can represent the real time difference relationship.

For most sectors, the corresponding time difference term of correlation coefficient is the same with that of KL divergence. Taking into account data errors, a difference of one or two months between two time difference terms is ignored and the corresponding time difference term of the correlation coefficient is considered to represent the time difference relationship. There is a consistent time difference term in each of the 37 sectors, while the remaining nine sectors have the opposite results. In the nine sectors, there are two time difference terms corresponding to the maximum correlation coefficient and the minimum KL divergence. By comparing the correlation coefficient and KL divergence corresponding to these two time difference terms, respectively, the time difference relationship between sectoral electricity consumption growth and economic growth can be adjusted the same. The time difference term will be adjusted according to the difference of the result and the more representative one will prevail. Table 3 gives the adjusted results.

From the results of time difference relationship in Table 3, 32 sectors have a negative value for the time difference term, the other 12 sectors have a positive value, and the remaining two sectors have a zero value. Taking into account the fact that the correlation coefficient and KL divergence together determine the time difference term, it is necessary to simultaneously consider the correlation coefficient and the KL divergence in analyzing the time difference relationship between sectoral electricity consumption growth and economic growth.

Table 3. The results of time difference relationship for 46 sectors.

Sector Code	Correlation Coefficient	KL Divergence	Time Difference Term	Sector Code	Correlation Coefficient	KL Divergence	Time Difference Term
S1	0.619918	27.71167	−17	S24	0.691304	20.67549	3
S2	0.655097	10.36398	2	S25	0.665386	46.474	−16
S3	0.207185	7.278065	−18	S26	0.496563	124.3153	−15
S4	0.864681	107.2604	2	S27	0.095785	81.47606	7
S5	0.732871	33.68715	3	S28	0.460174	17.91015	−1
S6	0.594579	28.22046	1	S29	0.49760383	38.6138725	−2
S7	0.378078	98.3009	16	S30	0.536092	21.47906	−16
S8	0.630699	7.389054	−15	S31	0.533781	22.70924	−15
S9	0.575556	8.951009	0	S32	0.38619	13.63726	5
S10	0.749904	21.43661	−16	S33	0.286228	18.4303	−15
S11	0.70244	22.61097	−15	S34	0.605046	29.40884	−15
S12	0.576845	19.61467	−17	S35	0.661358	20.22658	−17
S13	0.687926	38.41342	−15	S36	0.6171	174.1994	−16
S14	0.395387	88.62966	−16	S37	0.468803	25.48749	−15
S15	0.239763	33.19246	−15	S38	0.550531	42.83827	−16
S16	0.468987	31.97642	1	S39	0.303782	95.73843	−15
S17	0.396814	12.3994	1	S40	0.607474	6.35481	−17
S18	0.354165	9.585951	−2	S41	0.714993	74.42718	−16
S19	0.529657	38.77458	−15	S42	0.492442	6.529724	−15
S20	0.53711	16.75553	−16	S43	0.64067	9.093979	−16
S21	0.745179	40.93368	0	S44	0.586767	9.476812	−16
S22	0.672347	41.93267	1	S45	0.390882	16.23777	−16
S23	0.509891	39.54479	4	S46	0.582477	31.09458	−17

3.4. Discussions

The time difference relationship between sectoral electricity consumption growth and economic growth will change in different sectors even if they belong to the same industry. S1 belongs to agriculture with its electricity consumption growth ahead of economic growth. S2 to S31 belong to industry, of which 17 sectors have a leading relationship, 11 sectors have a lagging relationship, and the remaining two sectors have a synchronous relationship. The remaining 15 sectors from S32 to S46 belong to service. Almost all sectors have a leading relationship, except for S32, the sector of transport.

The co-integration relationship between total electricity consumption and economic growth has been verified in the existing literature [2,10,11,18], which means that there should be no obvious time differences between electricity consumption growth and economic growth. Sectoral electricity consumption growth has varying time difference relationships with economic growth, and our findings show different characteristics at both the industry level and sector level. As the total electricity consumption is composed of sectoral electricity consumption, the characteristics of the sector level may disappear at the macro level, which means the different relationships between sectoral electricity consumption growth and economic growth, such as leading relationship, lagging relationship and synchronization relationship, will form an overall relationship with economic growth. The sector with a high proportion of total electricity consumption has a noticeable impact on the time difference relationship between the total electricity consumption growth and economic growth. From the industry level, electricity consumption of agriculture and service changes ahead of the economic growth as a consequence of electricity consumption in major sectors varying faster than economic growth. On the contrary, the situation of industry is difficult to judge because each sector has quite different characteristics. In 2015, electricity consumption of industry accounted for 72.15% of total electricity consumption, while agriculture accounted for 1.84%, and service accounted for 12.90%. Thanks to a high proportion, which has been declining overall during the past decade, electricity consumption of industry, to a large extent, determines the relationship between total electricity consumption and economic growth.

The results of the time difference relationship does not show that the electricity consumption growth of all sectors has an obvious time difference relationship with economic growth. On the basis of the correlation coefficient greater than 0.5, this value is generally considered to indicate a correlation, a total of 29 sectors distributed in various industries can be selected for further analysis on the time difference relationship between sectoral electricity consumption growth and economic growth. There are 20 sectors whose electricity consumption growth has a leading relationship with economic growth, including one sector of agriculture, 10 sectors of industry, and nine sectors of service. All of the seen lagging sectors, and the remaining two synchronous sectors, come from industry. As shown in Figure 5, the time difference terms of all sectors present a state of aggregation viewed from the time difference term axis in spite of the difference existing in the correlation coefficient and KL divergence. The time difference terms of sectors with a leading characteristic are concentrated around 16 months with the distribution range from 15 months to 18 months. By contrast, the time difference terms of sectors with a lagging characteristic are scattered with a shorter length of time. These time difference terms are distributed within four months of which the longest one is four months from S23. Taking into account two synchronization sectors, the non-negative value of time difference terms vary from 0 to 4.

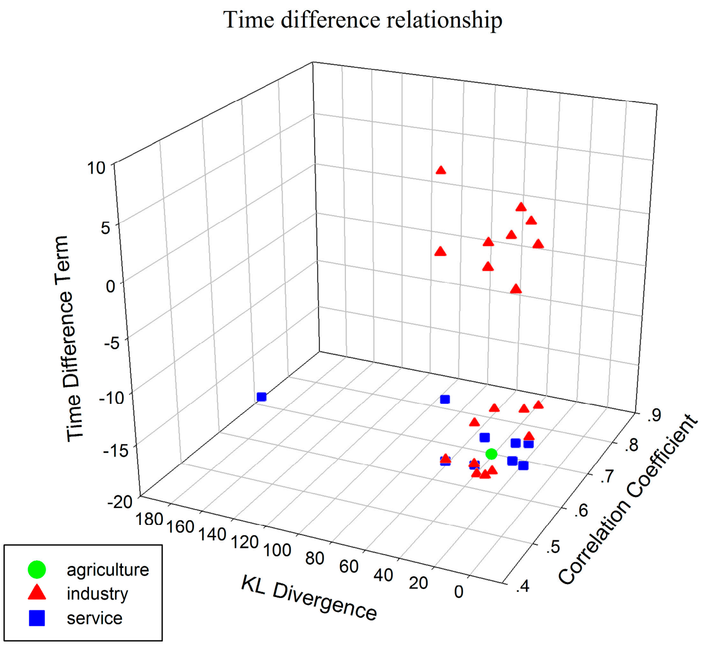

Figure 5. Time difference relationship results of selected sectors.

The time difference relationship between sectoral electricity consumption growth and economic growth varies in different sectors, while there are no obvious rules to follow. According to the results, whether from the sectors selected based on the correlation coefficient or from all sectors, the leading relationship accounted for the majority of all time difference relationships. Additionally, the time difference term of the leading relationship is generally longer than that of the lagging relationship. This shows that different sectors affect the relationship between the total electricity consumption and economic growth to different degrees. Sectors with lagging relationship are mainly from industry and have high electricity consumption, which will have a greater impact on the time difference characteristics of the total electricity consumption. The four major electricity consumption sectors, including manufacture of chemical raw materials and chemical products, manufacture of non-metallic mineral products, smelting and processing of ferrous metals, and smelting and processing of non-ferrous metals, corresponding to sector code S16, S20, S21, and S22, are often mentioned in the analysis of China's electricity consumption because they account for more than a quarter of the total electricity consumption in China. In 2015, these four sectors consumed 30.24% of the total electricity consumption, of which the sector of smelting and processing of ferrous metals consumed 511.58 TWH, which accounts for 9.22%. In these four sectors, S16 and S22 show the lagging characteristics. In contrast, S20 shows the leading relationship and S21 is synchronized.

The results indicate the time difference relationship between sectoral electricity consumption and economic growth, as well as the asynchronous nature of sectoral electricity consumption. The electricity consumption of different sectors show different degrees of correlation with economic growth. Industry has all three types of sectors with different time difference relationship, while agriculture and service have similar characteristic sectors, most of which show a leading relationship. In a sense, sectors with a leading relationship, a high correlation coefficient, and a small KL divergence can indicate the trend of economic growth in the future for some time through the change of its electricity consumption, while sectors with a lagging relationship, a high correlation coefficient and a small KL divergence can reflect the trend of changes in its electricity consumption associated with economic growth. The time difference relationship between electricity consumption growth and economic growth in these sectors will contribute to the exploration of the economic trends and formulation of relevant policies.

4. Concluding Remarks

It is vital for policy-makers to further explore the relationship between sectoral electricity consumption and economic growth on the basis of causal relationship results at a macro level so that proper policies can be formulated. Unlike most of the existing literature, this study focused on the time difference relationship between sectoral electricity consumption and economic growth through the correlation coefficient and KL divergence calculated by high-frequency monthly data. The growth rate of industrial value added is chosen as the proxy of economic growth and the monthly data of sectoral electricity consumption of 46 sectors is selected to complete the calculation and analysis. The time range of this study covers ten years from January 2006 to December 2015. Based on the time difference results consisting of correlation coefficient and KL divergence, the time difference relationship between economic growth and electricity consumption growth of each sector can be obtained. The findings of this study draw several main conclusions. Firstly, the time difference relationships show diversity at the sector level. The time difference characteristics of different sectors will form a kind of overall characteristic between economic growth and total electricity consumption. Secondly, not all sectors have a remarkable correlation between sectoral electricity consumption and economic growth. The correlation coefficient and KL divergence results are different among sectors and only part of them has reasonable values to describe the time difference relationship. Thirdly, the results present both diversity and aggregation at industry level. Sectors whose electricity consumption growth is lagging behind the economic growth mainly concentrate in industry. While leading sectors and synchronous sectors are distributed in three industries. Based on the results, the relationship between sectoral electricity consumption and economic growth can be further explored and described from a new perspective. Further, the trend of economic development and the growth of sectoral electricity consumption can be predicted to some extent. There are still some limits of this study associated with the methods and data. The proxy data and processing of vacancy data will bring some reasonable error. The study takes time series data from 2006 to 2015 as a whole with a stable relationship, without taking into account sectoral changes in electrical characteristics. Data accuracy, as well as the impact of industrial restructuring and electricity efficiency improvements, will be considered in further development of the study.

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Appendix

Code	Sector Name
S1	Farming
S2	Mining and washing of coal
S3	Extraction of petroleum and natural gas
S4	Mining and processing of ferrous metal ores
S5	Mining and processing of non-ferrous metal ores
S6	Mining and processing of nonmetal ores
S7	Mining of other ores
S8	Manufacture of foods, beverages and tobacco
S9	Manufacture of textiles
S10	Manufacture of apparel, leather and related products
S11	Processing of timber and manufacture of furniture
S12	Manufacture of paper and paper products
S13	Printing and recorded media
S14	Manufacture of articles for culture, education, art, sports and entertainment
S15	Processing of petroleum, coking, processing of nuclear fuel
S16	Manufacture of chemical raw materials and chemical products
S17	Manufacture of medicines
S18	Manufacture of chemical fibers
S19	Manufacture of rubber and plastics
S20	Manufacture of non-metallic mineral products
S21	Smelting and processing of ferrous metals
S22	Smelting and processing of non-ferrous metals
S23	Manufacture of metal products
S24	Manufacture of general and special purpose machinery
S25	Manufacture of transportation, electrical and electronic equipment
S26	Other manufacturing
S27	Comprehensive use of waste resources
S28	Production and distribution of electric power and heat power
S29	Production and distribution of gas
S30	Production and distribution of water
S31	Construction
S32	Transport
S33	Storage
S34	Postal services
S35	Telecommunications and other transmission services
S36	Software and information technology services
S37	Wholesale and retail trades
S38	Accommodation and catering
S39	Finance
S40	Real estate
S41	Leasing, commercial, resident and other services
S42	Scientific research and polytechnic services
S43	Administration of water, environment and public facilities
S44	Education, culture, sports and entertainment
S45	Health care and social work
S46	Public administration, social organizations and international organizations

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