Regional Energy Consumption Differences and Neural Mechanism of Environmental Risk Decision Making in China

Yixin Xing

ABSTRACT
The environmental crisis caused by excessive energy consumption is the main problem that restricts current social development. When facing environmental risks, people's risk decision is deeply influenced by cognitive neural mechanism. This paper measured the conventional energy consumption differences of three regions in China and its evolving trends from 1996 to 2015 with the GDP-weighted Theil Index. The results show that in the two decades, the overall difference in Chinese conventional energy consumption decreased annually, and the economic development level and conventional energy consumption evolved in the same direction. Specifically, the overall difference in regional conventional energy consumption in China mainly comes from inter-regional differences. As for the intra-regional differences, under the weight of GDP, it mainly results from internal differences in the eastern region, while under the population weight, the western region surpasses the central and eastern regions to be the largest contributor to the intra-regional differences. In the face of energy and environmental risks, people's risk decisions are closely linked to cognitive neural mechanisms, which are based on the cerebral cortex and amygdala.

Key Words: Conventional Energy Consumption, Theil Index, Regional Differences, Cognitive Neural Mechanism

DOI Number: 10.14704/nq.2018.16.6.1582

Introduction
Energy, the material foundation of modern civilization and the power source for economic development, is vital to the economic scale expansion and development process acceleration. At present, China still depends heavily on primary conventional energy consumption, while European and other countries are driving to use renewable energies, improve energy efficiency and so on (Borchiellini et al., 2017; Lassandro and Turi, 2017; Trancossi et al., 2016; Zaccone et al., 2017). According to China Energy Statistical Yearbook 2016, the total conventional energy consumption in China in 2015 was 4.3 billion tons of standard coals, an increase of 7.2 folds in 35 years compared with 1981 when the sixth five-year plan was started. However, along with the increasing conventional energy consumption in China, the shortage of energy and resources and the worsening of ecological environment are becoming more serious, posing severe challenges to China's sustainable development. In the face of energy and environmental risks, making the right decision is of vital importance to achieve carbon emission reduction and a comprehensive and coordinated development of energy, economy and environment (Elmore et al., 2008; Zhang et al., 2015). Cognition, emotion and neural mechanism are decisive in making risky decisions. Risk decision making refers to the process of making decisions by weighing the subjective expected value of different options in uncertain situations with different options and probabilities (Kahneman, 2003). From the perspective of
Decision Neuroscience, the neural mechanism behind risk decision making is well explained by the dual-systems theory (Kahneman, 2003) and other models. The relevant researches revealed the mechanism of risk-based decision-making in economic management (Zhang, 2018), the evaluation and decision-making of product premium based on actual materials of product premium in the market (Zhang, 2018) and so on.

Based on the analysis of energy consumption in different regions, this paper discussed cognitive neural mechanisms of risk decision making behaviors, in order to make a forward-looking prediction and response to people's behavior of environmental risk decisions.

But it should be noted that due to the vast territory of China that shows obvious differences in the regional resource endowments and economic structure (Qi et al., 2007), targeted and differentiated energy conservation policies shall be formulated to substantially improve the energy efficiency and ease the pressure on energy consumption in our country, whose top priority is to study the energy consumption differences in various regions.

This paper introduced the Theil index in econometric statistics for the quantitative analysis of the spatial distribution differences of energy consumption in China. Theil index, proposed by the econometrician Theil Henri in 1967 in line with the entropy concept of the information theory (Theil, 1967), is used to calculate and analyse the differences in economic development and income levels among regions (Theil, 1989; Theil and Seale, 1994; Theil and Moss, 2000). Later, Theil index was introduced and applied to energy-related issues by scholars. Avik Sinha, through the Theil index, examined the trilateral association between SO2 and NO2 emission, inequality in energy intensity and economic growth (Sinha, 2016). Also, he measured differences in renewable energy production between member countries of the Organization for Economic Co-operation and Development (OECD) from 1980 to 2011 and found that the differences in energy production between and within regions gradually narrowed, with the contribution rate of inter-regional differences always greater than that of intra-regional differences (Sinha, 2017). Also, Theil index method was adopted to analyse the differences in global primary energy consumption and the differences in energy consumption across and within regions (Alcantara and Duro, 2004; Duro and Padilla, 2010). Lorena Remuzgo and Jose Sarabia used Theil index to analyse the determinants of inequality in the global distribution of CO2 emissions across the regions considered during the period 1990-2010 (Remuzgo and Sarabia, 2015).

In recent years, domestic and foreign scholars have carried out much analysis on the differences in energy consumption among different regions in China and their influencing factors through Theil index. For example, Zhang Shixiang et al., (2013) analysed the energy consumption disparities among 30 provinces, municipalities and autonomous regions in China from 1995 to 2010, whose result shows that the discrepancy in energy consumption among different regions in China gradually narrowed, and the overall differences in energy consumption are mainly attributed to the intra-regional differences. Zhang and Zhao (2014) analysed the regional differences in energy consumption in China from 1986 to 2011 and their changing trends, leading to the conclusion that energy consumption and population have the strongest similarities in development, and differences within the regions are the main sources of energy consumption differences. Theil index also was used to study urban energy consumption disparities in China, which concluded that cities with high energy consumption are mainly located in economically developed regions and focus on electricity and petroleum consumption, while cities with high per capita energy consumption are mainly in central and western regions and focus on coal consumption. Therefore, the difference in energy consumption among the three major regions is the main reason for the difference in overall energy consumption in China (Zhang et al., 2011). In order to measure the spatial disparities in conventional energy consumption among various regions of China and the changing trends, this paper explored the differences in the similarities of the growth of conventional energy consumption and that of economic level and population respectively in three regions through the Theil index. At the same time, this paper researched the contribution rates of the intra-regional differences and inter-regional differences to the overall differences, and accordingly provided reference for the implementation of differentiated regional energy policies according to local conditions.
Methods
Data Source and Processing
In accordance with the division standard of the National Bureau of Statistics of China, the eastern region includes 11 provincial-level administrative regions of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region consists of 8 provincial-level administrative regions of Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region covers 12 provincial-level administrative regions of Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, and Inner Mongolia. Due to the lack of energy consumption data in Tibet Statistical Yearbook, the western region in this paper contains only 11 provincial-level administrative regions except the Tibet Autonomous Region. The energy consumption data used in this paper are from China Energy Statistical Yearbook 2016, and the economic growth and population growth data come from China Statistical Yearbook 2016 and China Compendium Statistics 1949-2008, as well as the statistical yearbooks of various provinces, municipalities and autonomous regions. In order to make prices comparable, this paper, taking 1996 as the base period, converted GDP into real value based on the annual GDP price indexes of various provinces, municipalities and autonomous regions, and unified the energy consumption unit as 100 million tons of standard coal.

Measuring methods
In this paper, the Theil index method was used to measure the differences in energy consumption among different regions in China and among provinces and cities within one region. Drawing on the research achievements of the predecessors, this paper designed the formula to calculate the Theil index for the regional energy consumption differences as follows:

$$T = \sum_{i=1}^{N} \frac{E_i}{E} \ln \left( \frac{E_i/E}{X_i/X} \right)$$  \hspace{1cm} (1)

In Formula (1), T refers to the Theil index, i to the province, N to the total number of provinces, E to the energy consumption amount, and X to the weight variable used to calculate the Theil index, namely the variable for the research on its relations to energy consumption, which refers to GDP (G) or population (P). The Theil indexes of the two are respectively expressed as T(GDP) and T(P).

In line with the Theil index formula, if T=0, there is no regional difference in energy consumption. If T≠0, there is regional difference in energy consumption, and the greater absolute value of T refers to greater regional difference in energy consumption. When X is set as the same variable, the larger the T is, the greater the regional energy consumption difference is. If X is set as different variables, compare the corresponding Ts. Specifically, if T(GDP)> T(P), it means that the growth of regional energy consumption is more similar to that of population with higher matching, concluding that energy consumption is more affected by population growth.

On the other hand, Theil index can be decomposed into two parts of $T_w$ and $T_b$ as follows:

$$T = T_w + T_b \hspace{1cm} (2)$$

$$T_w = \sum_{i=1}^{M} \left( \frac{E_i}{\Sigma E} \right) T_{wj} = \sum_{i=1}^{M} \left( \frac{E_i}{\Sigma E} \right) \sum_{j=1}^{N} \left( \frac{E_{ij}}{E_j} \right) \ln \left( \frac{E_{ij}/E_j}{X_{ij}/X_j} \right) \hspace{1cm} (3)$$

$$T_b = \sum_{j=1}^{M} \left( \frac{E_j}{\Sigma E} \right) \ln \left( \frac{E_j/E}{X_j/X} \right) \hspace{1cm} (4)$$

In the Formula (2), (3) and (4), $T_w$ and $T_b$ refer to the intra-regional and inter-regional Theil index respectively, j to the region, Nj and M to the total number of provinces and regions in the j region respectively, $T_{wj}$ to the Theil index of the j region, $E_0$ to the energy consumption amount of the i province in the j region, $E$, $E_0$ and Ej to the energy consumption amount of all, the i province and the j region respectively, $X_i$ to the GDP or population of the i province in the j region, and X, Xi, and Xj to the total amount of variables, the amount of the i province and the total amount of the j region respectively.

The Theil index can also be applied for the analysis of inter-regional and intra-regional contribution rate. The inter-regional contribution rate ($W_b$) is the contribution of the inter-regional differences to the total differences, while the intra-regional contribution rate ($W_w$) refers to the contribution of the intra-regional differences. And the contribution rate of each sub-region within one region ($W_i$) can be studied. The three formulas are:
Results and Analysis

Theil Index of Conventional Energy Consumption

The value of Theil index reflects the degree of the differences in energy consumption of the regions under this research, with their dynamic changes per year shown clearly in the time series. According to Formula (1)-(4), the total energy consumption, GDP and population data of the whole country and 30 provinces (autonomous regions and municipalities) from 1996 to 2015 are based to calculate the Theil index of Chinese regional energy consumption differences in China weighted by the GDP and population respectively, namely \( T(GDP) \) and \( T(P) \). Figure 1 shows the Theil index evolving trends under the two weights from 1996 to 2015 in the form of line chart.

\[
W_b = \frac{T_b}{T} \quad (5)
\]

\[
W_w = \frac{T_w}{T} \quad (6)
\]

\[
W_j = (E_j / E) * \frac{T_w}{T} \quad (7)
\]

From Figure 1: (1) From 1996 to 2015, the Theil indexes of China's energy consumption under two weights show an overall downward trend with basically the same evolving trend. However, the energy consumption intensity shows unstable changing trend with repeated rising and falling fluctuations. Among them, the two types of Theil indexes started to drop significantly in 1996 and reached the first lowest point in 1999, due to the successive implementation of China Energy-saving Technical Program in 1996 and Energy Conservation Law of the People’s Republic of China in 1998 that narrowed regional energy consumption differences. But the effects of the two policies did not last long, and the two types of Theil indexes both fluctuated and reached the minimum value in 2005. During the implementation of the 12th Five-Year Plan, China focused on the "transformation" in the growth mode, the development strategy, and the industrial policy. Guided by such "transformation" policies, China's energy consumption growth slowed down significantly, with the energy consumption structure substantially improved, leading to major decline of the two types of Theil indexes from 2010 to 2015. Therefore, the regional differences in energy consumption in China are greatly affected by the policies, among which the industrial adjustment, especially for highly-energy-intensive industries, contributes most to the differences. (2) The GDP-weighted Theil index shows higher similarity to the energy consumption in all regions of China. As can be seen from Figure 1, \( T(P) > T(GDP) \) before 1998, which shows that the proportion of energy consumption is more similar to that of population in all regions in China. However, since 1998, \( T(GDP) \) has gradually increased while \( T(P) \) began to decline. This indicates that with the rapid economic and social advances in China, the proportion of energy consumption in all regions out of the total national consumption is closer to the proportion of GDP in all regions out of the total national GDP.

Analysis of Regional Contribution Rates

Based on Formula (5)-(7), the contribution rates of each segment to the regional energy consumption differences can be calculated. Takes the Theil Indexes under GDP Weights as an example, as Table 1 shows.

Table 1 shows:

(1) Under the GDP weights, the overall differences in regional energy consumption are mainly attributed to inter-regional differences. During the period surveyed, the GDP-weighted inter-regional differences contribute at the rate of 50% to 70%, which is less than the intra-regional contribution rate only between 2003-2007 and 2013-2015. This is mainly due to the vast land of China and huge regional disparities in the economic level, energy endowment and consumption. The eastern region sees rapid economic growth, sound industrial development, dense population with a large amount of energy consumption, while the central and western regions have lower demands for energy consumption due to the weak industrial foundation, lagging industrial development and sparse population. However, it is noteworthy that since 2014, the regional contribution rates under
GDP weight has declined, and the intra-regional contribution rate has risen to varying degrees, exceeding the inter-regional contribution rates, indicating that the intra-regional differences in energy consumption in China are gradually narrowing. (2) Concerning the intra-regional Theil indexes, under the GDP weights, the contribution rates of the differences in the eastern region are relatively high, basically maintaining between 15% and 40%, while those of the differences in the central and western regions are relatively low between 10% -25%. However, it is noteworthy that the contribution rates of central and western regions have been rising steadily since 2012, indicating that with the development of the central and western regions, the gap between the proportion of energy consumption and GDP has been constantly widening, and the provinces within the regions have seen increasing dependence on energy in their economic development.

### Table 1. Contribution rates of the Theil index under GDP weights

<table>
<thead>
<tr>
<th>Year</th>
<th>Intra-regional contribution rate (%)</th>
<th>Inter-regional contribution rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>14.2 8.2 8.5 30.9</td>
<td>69.1</td>
</tr>
<tr>
<td>1997</td>
<td>14.8 10.5 7.4 32.7</td>
<td>67.3</td>
</tr>
<tr>
<td>1998</td>
<td>14.6 8.7 8.8 32.1</td>
<td>67.9</td>
</tr>
<tr>
<td>1999</td>
<td>17.6 11.1 10.5 39.2</td>
<td>60.8</td>
</tr>
<tr>
<td>2000</td>
<td>18.5 8.9 9.6 37.0</td>
<td>63.0</td>
</tr>
<tr>
<td>2001</td>
<td>18.9 13.6 9.5 42.0</td>
<td>58.0</td>
</tr>
<tr>
<td>2002</td>
<td>17 11.1 7.6 35.7</td>
<td>64.3</td>
</tr>
<tr>
<td>2003</td>
<td>23.4 12.3 12.2 47.9</td>
<td>52.1</td>
</tr>
<tr>
<td>2004</td>
<td>31.7 13.4 16.2 61.3</td>
<td>38.7</td>
</tr>
<tr>
<td>2005</td>
<td>41.5 18.9 17.6 78.0</td>
<td>22.0</td>
</tr>
<tr>
<td>2006</td>
<td>37.1 17.3 15.5 69.9</td>
<td>30.1</td>
</tr>
<tr>
<td>2007</td>
<td>25.2 11.7 10 46.9</td>
<td>53.1</td>
</tr>
<tr>
<td>2008</td>
<td>19.3 8.3 7.5 35.1</td>
<td>64.9</td>
</tr>
<tr>
<td>2009</td>
<td>18.4 8.1 7.2 33.7</td>
<td>66.3</td>
</tr>
<tr>
<td>2010</td>
<td>17.4 7.1 6.7 31.2</td>
<td>68.8</td>
</tr>
<tr>
<td>2011</td>
<td>16.9 7.2 8.1 32.2</td>
<td>67.8</td>
</tr>
<tr>
<td>2012</td>
<td>14.2 6.9 8.0 29.1</td>
<td>70.9</td>
</tr>
<tr>
<td>2013</td>
<td>23.6 16.3 18.6 58.5</td>
<td>41.5</td>
</tr>
<tr>
<td>2014</td>
<td>18.7 14.0 15.9 48.5</td>
<td>51.5</td>
</tr>
<tr>
<td>2015</td>
<td>33.6 24.3 33.1 91.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

### Conclusions and Discussion

Based on the Theil index, this paper studied the regional differences in energy consumption in China from 1996 to 2015. And the Theil indexes under two weights for three regions further lead to the following conclusions:

(1) Since 1995, the overall energy consumption Theil indexes under both GDP and population weights have been decreasing year by year, indicating increasingly narrowed gap of energy consumption among regions in China. If T(P) >T(GDP), it shows that the Theil index weighted by GDP is more similar to the energy consumption in various regions of China, and the energy consumption and economic development level evolve in the same trend. Therefore, we should further reduce the energy consumption required by per unit of GDP and continue to adhere to the development of a resource-saving and environment-friendly society so as to reduce the regional differences in energy consumption in our country.
The regional energy consumption differences in our country mainly originate from that in three major regions. As for the intra-regional differences, under the GDP weight, the inter-provincial differences within the eastern region contribute most, while under the population weight, the western region overtakes the central and eastern regions to be the largest contributors. As the time goes, the contribution rates of the western region under both weights are on the rise, with the tendency of surpassing the eastern and central regions in the future, displaying widening inter-provincial energy consumption disparity in the western region. Therefore, we should differentiate economic development strategies for the eastern, central and western regions, namely further energy efficiency improvement for the eastern and central regions with less intra-regional differences and strengthening financial and technical support for the western region with widening intra-regional differences to avoid economic growth at the expense of energy consumption.

(3) When facing energy and environmental risks, researches in the field of decision neuroscience indicated that emotional and social cognitive neural control network played a vital role in people’s risk decision making behaviours.

Acknowledgments

I would like to express my sincere gratitude to all those who helped her during the writing of this paper. This paper was supported by the “Research Innovation Program for College Graduates of Jiangsu Province” (KYLKX_0410) and the “Fundamental Research Funds for the Central Universities” (2014B29514).

References


