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Regional Disparity and Convergence of Electricity Consumption in China: A Distribution Dynamics Approach

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Abstract

One critical factor that affects China's achievement of its peak emission by 2030 is total electricity demand. The aim of this study is to examine regional disparity in electricity consumption in China. The analysis is based on a panel database which is compiled at the provincial level. A distributional dynamics approach is then employed to reveal the trend and movement of each province within the distributions in different regional groupings. The mobility probability plot (MPP) is also employed to provide detailed information on the probability of change in electricity consumption. The results demonstrate significant divergence presents across provinces, over time and within different regional groups. The results can pinpoint the transition mechanism within each region so that appropriate energy policy can be formulated to accommodate future demand in electricity for different regions in China. The results suggest that regional specific energy efficiency policy is needed.

1. Introduction

Where would be the steady state demand is an important question for national and international energy and environmental policy makers. Whether cross-sectional differences or convergence in energy-related measures across countries is an actively debated issues in the energy economics literature (Kim, 2015). While there are many studies on the factors behind reducing energy intensity globally, little attention has been paid on whether differences in energy intensity diminish over time, and if convergence can be achieved. However, such convergence studies are important in terms of mapping out whether there is a diffusion of energy-related technologies across regions, and what regions need to be prioritized in the improvement of efficiency (Herrerias and Liu, 2013).

China is a fascinating case study of energy economics issues due to its impressive economic performance in the past few decades (Herrerias and Liu, 2013) and its associated dramatic increase of energy demand. Despite of remarkable growth in electricity consumption, China's per capita electricity consumption in 2014 was around 3927 kWh, only slightly higher than the world average of 3128 kWh, 30% of that of the US, and 50% of the level of the Japan, the most energy efficiency country in the world (World Bank, 2017). There is a huge diversity in electricity consumption per capita across province in China: ranging from 1250 kWh in Tibet to 13149 kWh in Ningxia in 2015. Such divergence in energy intensity across subnational units challenges the national governments' credibility to reduce their reduction targets of energy or emissions (Herrerias, 2012).

Whether electricity consumption converges across provinces is an academic and policy question that matters to China and the world. Since China is the world's largest CO_2 emitter, its future change in electricity demand will not only affect its international commitment of reaching the peak CO_2 emission by 2030, but also affect the achievement of global target of CO_2 emissions. Convergence studies on subnational levels are often focused on big countries such as China (Wang, 2011) and USA (Mohammadi and Ram, 2017; Payne et al., 2017) .

The aim of this paper is thus to investigate the process of convergence of per capita electricity consumption in the Chinese provinces over the period 2000–2015 with the application of a distribution dynamics approach. Distribution dynamics, or transitional dynamics approach is employed to reveal the trend and movement of each province within the distributions in different regional groupings. The convergence studies at the subnational level have important policy implications. The information on the distribution of electricity consumption amongst the provinces can help the government in prioritizing national energy and environmental policy across

the country. The information can also reveal future development of electricity consumption; thereby enabling the government to allocate scarce resources in a more efficient way by providing incentives and support to the provinces most in need. The government can also encourage investment in these provinces, and promote knowledge diffusion, particularly for the region with low energy efficiency or high emission intensity.

This paper makes several contributions to the literature by examining the convergence of electricity consumption in China. First, we try to examine the evolution of per capita electricity consumption across time in details. We divide the dataset into several transition episodes. By investigating the difference in these episodes, we can understand the change in the transitional dynamics over time. As argued by Herrerias and Liu (2013), this is fairly important for China as the electricity consumption in China is still in the process of transformation; therefore, the information on the change by distribution dynamics proves especially valuable for the policy makers. Second, we examine the regional difference amongst different economic zones. This information not only can reveal the severity of the disparity in consumption, but also offer detailed information on the relationship between geographical groupings and electricity consumption. The third novel aspect is the employment of mobility probability plots (MPPs) in our study. The results can pinpoint the transition mechanism within each region so that appropriate energy policy can be formulated to accommodate future demand in electricity for different regions in China.

The paper proceeds as follows. The next section review studies on convergence in the literature focusing on electricity consumption convergence in intensity, per capita or both. Section 3 introduces the data and briefly discusses its main characteristics. Section 4 presents the methodology, followed by the results in Section 5. The last section concludes the paper with policy implications.

2. Literature Review: Per Capital Electricity Convergences

Convergence, a concept that comes from economic growth literature, has been applied to other fields, including energy-economics (Herrerias, 2012). Some studies try to link the economic concept with energy issues. For example, Sheng and Shi (2011) and Sheng and Shi (2013) examine the role of energy market integration on economic growth convergence.   Wesley Burnett and Madariaga (2017) extend a neoclassical growth model by including the accumulation of physical capital and energy consumption. Based on that theoretical model, they examine the implications

for convergence in economic growth and energy intensity. Jakob et al. (2012) investigate the dynamic patterns of energy use with the development of economic change, through a dataset of countries over the period 1971–2005. Others apply the concept to energy economics, such as energy intensity convergence (Ezcurra, 2007; Le Pen and Se´ vi, 2010; Liddle, 2009; Wang, 2011), per capita energy consumption convergence (Fallahi and Voia, 2015; Payne et al., 2017) and energy market convergence in terms of prices (Ma and Oxley, 2012; Sheng et al., 2013).

In terms of methodology, there are two kinds of convergence employed in the econometrics analysis on economic growth, namely σ-convergence and β-convergence (Barro and Sala-i-Martin, 1995). σ-convergence indicates that the dispersion of real per capita income across countries tends to fall over time while β-convergence applies if a poor country or region tends to grow faster than a rich one (Sheng and Shi, 2013). Whether energy intensity converges across countries over time or not is an topic that has not been well studied, in particular when compared with related topics like environment and growth (Herrerias, 2012; Le Pen and Se´ vi, 2010) .

Studies on convergence in per capita energy use have been started to emerge recently. Payne et al. (2017) investigate the convergence of per capita renewable energy consumption across U.S. states. Mohammadi and Ram (2017) examine convergence in per-capita energy consumption across the US states in the period 1970–2013. Using both parametric and non-parametric approaches, they have not found convergence across U.S. states in per-capita energy consumption and attribute this lack of convergence to variations in structural factors. Both Fallahi and Voia (2015) and Meng et al. (2013) investigate the convergence in per capita energy use among OECD countries.

Among the limited literatures on energy-intensity convergence across Chinese provinces, there is no consistent finding (Herrerias and Liu, 2013). While earlier studies demonstrates declining trend (Ma and Stern, 2008; Zhang, 2003), later studies reveal other way around (Zhao et al., 2010). Herrerias et al. (2017) investigate the patterns of residential energy consumption with break-down between urban and rural residents and their club convergence analysis, and find different steady-states between rural and urban residents.

Unlike energy consumption, electricity consumption per capita is often used in the literature due to its role in determining economic welfare or development (Kim, 2015). The electricity consumption is important (i.e., the Li Keqiang Index for industrial electricity increase) for policy makers when evaluating economic development goals. Per capita electricity consumption in developing countries is often low and increasing living quality will demand more electricity. Many previous

studies such as Ferguson et al. (2000), Jakob et al. (2012), and Joyeux and Ripple (2007), have shown that per capita electricity consumption is strongly associated with economic development and electricity is a better indicator than primary energy to measure differences in standard of living over time and across countries. In fact, the world electricity consumption, in terms of intensity and per capita, seems to exhibit a long-run upward trend (Kim, 2015). One UN report (AGECC, 2010) declares that the minimal need of electricity consumption for a modern society is 2000 kWh per capita per year. A few studies e.g., (Liddle, 2009), suggest that the change of a country's energy structure, more specific shifts to electricity, is one of the dominant factors that have improved energy efficiency and slowed down per capita energy consumption growth.

A list of studies on electricity consumption that we have founded in the literature is summarized in Table 1. In the case of IEA countries, Mohammadi and Ram (2012) and Liddle (2009) find evidence of electricity intensity convergence. Kim (2015) investigates the dynamic behaviour of electricity consumption convergence patterns of a global data. He finds that countries tend to converge towards a common trend for electricity intensity, but no overall convergence for per capita electricity consumption. By using residential per capita electricity consumption, Maza and Villaverde (2008) explore worldwide differences on this variable between 1980 and 2007 and find a weak process of electricity consumption convergence. Herrerias and Liu (2013) study the stochastic electricity-intensity convergence across Chinese provinces with the application of unit root tests and club convergence and find there are more than one convergence club. Borozan (2017), using the panel unit tests with and without structural break(s), the convergence hypothesis in relative per capita electricity consumption series is tested across Croatian regions during the period 2001–2013. The results are mixed, depending primarily on the consumption sector considered and the test applied. Based on the results derived from the sector-disaggregated time series of electricity consumption, they emphasize the necessity to formulate regional specific energy policy.

Table 1   Studies on Convergence of Electricity Consumption

Study	Indicators	Data	Methodology
Maza and Villaverde, 2008	Per capita, residential	Cross country, 1980–2007	σ and β convergence; density functions and stochastic kernels
Liddle, 2009	intensity	IEA/OECD countries, 1960 to 2006	sigma-convergence

Mohammadi and Ram, 2012	per-capita	Cross country, 1971–2007	OLS, β-convergence
Herrerias and Liu, 2013	Intensity	Chinese province, 2003-2009	Unit root tests and club convergence
Kim, 2015	Intensity, per capita	109 countries, 1971–2009	clustering analysis, log t convergence test
Borozan 2017	per capita	Croatian regions, 2001–2013	panel unit tests

Overall, the dynamic aspects of electricity consumption distribution have received relatively less attention (Kim, 2015). Furthermore, those kinds of parametric methods, although provide a summary of the statistic of interest, ignores the information on multimodal distribution   (Quah, 1993b) and thus the results could be deceiving (Quah, 1997). In addition, this traditional approach only provides a summary of the statistics, but could not provide the much needed information of the entire shape of the distribution and its changes (Quah, 1993b).

This study applied the distribution dynamics approach. This approach allows us to understand the transitional dynamics of electricity consumption per capita across time. This will enhance the knowledge of intra-distribution mobility for the provinces. It can even offer detailed information on each spatial grouping by revealing their distinguishing features in terms of energy efficiency. Moreover, this approach can be used to offer a forecast for the shape of the distribution of electricity consumption intensity levels in the long-run, which is an issue particularly relevant from the energy policy perspective.

3.   Electricity Consumption in China's Provinces

The data used in this study is compiled from the China Statistical Yearbooks (State Statistical Bureau, 2001- 2016), and it covers the period from 2000 to 2015. The data of electricity is measured as the relative electricity consumption per capita. Electricity consumption in each province is first divided by the registered population in that province to calculate the consumption per capita. Similarly, the national average level of consumption is measured as the total electricity consumption for the nation divided by the national population. After that, the individual electricity consumption of each province is then divided by the national mean to work out the relative electricity consumption per capita (RECPC). The table of descriptive statistics

for that variable is presented in Table 2.

Table 2   Descriptive Statistics of Variable RECPC

Variable	Obs.	Mean	Std. Dev.	Min	Max
RECPC	488	1.130	0.636	0.212	3.230

In the first stage of analysis, distribution dynamics approach is employed for all the provinces so as to offer an overall picture of the pattern and trend of electricity consumption in China. Then the database is separated into three time episodes. This can reveal the changes in distribution dynamics for the underlying distribution across time. After that, the whole database is then divided into four datasets as defined by the four economic zones, namely, the Eastern, Central, Western, and North-eastern zones. This can offer detailed information on the transitional dynamics for the provinces in each economic zone. Given that the economic development levels are different among the economic zones; this analysis may reveal the relationship between electricity consumption and economic development.

Finally, the dataset is divided into high temperature provinces and low temperature provinces according to the mean temperature of each provincial capital. The mean temperature of the provincial capital is compared with the average temperature of all the provinces, and if the mean temperature of a provincial capital is higher than the national average, then this province is classified as a high-temperature province. This additional analysis can reveal crucial information which is not available from the analysis derived from the traditional classification of the four economic zones. Since the traditional classification cannot distinguish the difference in latitude, and electricity consumption may be affected by the temperature within a province; therefore, it is crucial to compile this dataset so as to examine the impacts of temperature on electricity consumption. This can complement the traditional analysis and provide a new angle in examining the electricity consumption in China.

4. Method

Distribution dynamics analysis was developed by Quah (1993a), and it is a useful and versatile tool for studying the transitional dynamics of electricity consumption. This approach can be divided into the stochastic kernel approach and the traditional Markov chain analysis approach. The former is an improved version of the latter, and the former was developed to circumvent the issue of demarcation of state of the

traditional Markov chain analysis. Given the stochastic kernel approach is better, so it is used in this paper. The analysis is based on a bivariate kernel estimator:

$$\hat{f}(x,y) = \frac{1}{nh_1h_2} \sum_{i=1}^{n} K(\frac{x-X_{i,t}}{h_1}, \frac{y-X_{i,t+1}}{h_2})$$ (1)

where n is the number of observations, h_1 and h_2 are the bandwidths, K is the normal kernel function, x is a variable representing the RECPC of a province at time t, y is a variable representing the RECPC of that province at time t+1, $X_{i,t}$ is an observed value of RECPC of a province at time t, and $X_{i,t+1}$ is the observed value of the RECPC of that province at time t+1. The values of the bandwidths were calculated by the procedure proposed by Silverman (1986).

It is worth noting that the actual distribution of electricity consumption in China is not like a normal distribution; but it is a skewed distribution which has a long right tail. This can greatly affect the accuracy of the estimation process of the stochastic kernel as over-smoothing and under-smoothing may occur in different regions of the distribution. It can be expected that under-smoothing may occur in the regions with only a few entities, whereas over-smoothing may appear in regions with many entities. The technique of adaptive kernel with flexible bandwidth is thus employed to take this issue into consideration (Silverman, 1986).

Assuming that the evolution is time invariant and first order, so that the distribution at time t +τ only depend on the distribution at time t only, and does not depend on any previous distributions, then the distribution at time t +τ is:

$$f_{t+\tau}(z) = \int_0^\infty g_\tau(z|x) f_t(x) dx$$ (2)

where $g_\tau(z|x)$ is the transition probability kernel which maps the distribution from time t to t +τ, $f_t(x)$ is the kernel density function of the distribution of RECPC at time t, and $f_{t+\tau}(z)$ is the τ-period-ahead density function of z conditional on x.

By employing equation (2) repeatedly, the long run steady-state distribution which is called the ergodic distribution can be derived by:

$$f_\infty(z) = \int_0^\infty g_\tau(z|x) f_\infty(x) dx$$ (3)

where $f_\infty(z)$ is the ergodic density function when τ is infinite.

The technique of the mobility probability plot (MPP) is also employed in this study so as to provide detailed information on the probability of change in electricity consumption. This technique was first developed by Cheong and Wu (2015). It was employed in many macroeconomic research areas, for example, industrial output (Cheong and Wu, 2015), rural household income (Li and Cheong, 2016), housing price and affordability (Cheong and Li, 2017; Li et al., 2017) and also in energy economics such as carbon dioxide emissions (Cheong et al., 2016; Wu et al., 2016).

The MPP is expressed as percentage. It represents the net upward mobility probability of RECPC for each province, and so it ranges from -100 to 100. The MPP can be calculated as $p(x)$:

$$p(x) = \int_x^\infty g_\tau(z|x)dz - \int_0^x g_\tau(z|x)dz \qquad (4)$$

The MPP shows the net probability of increasing consumption, so if a province has a positive MPP, it means that the province has a high tendency to increase its electricity consumption in next year. However, if a province has a negative MPP, it means that the province has a high tendency to reduce its consumption in next year. Therefore, one can make a forecast of the consumption pattern for each province by observing whether the MPP is positive or negative.

5. Results

5.1 All Regions

Stochastic kernel analyses are performed to compute the transitional dynamics for electricity consumption from 2000 to 2015. Figure 1a shows the three-dimensional plots of electricity consumption in all regions, while Figure 1b displays the associated overhead view of the contour map. The width of the transition probability kernel for all regions are widely dispersed with the density mass concentrated along 45 degree diagonal line. There are two peaks in Figure 1b, indicating that electricity consumption changes may be clustered with two groups. Cluster 1 is concentrated around 0.65, while Cluster 2 is concentrated around 1.31. Cluster 1 is more densely concentrated, indicating that a major of regions' electricity consumption tend to be lower than the national average.
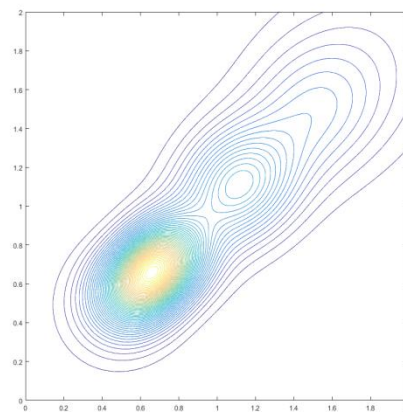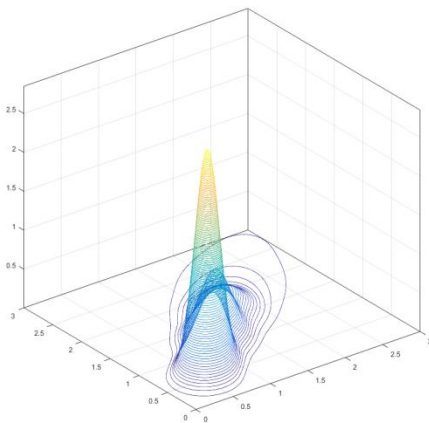
a) **Three Dimension Plot**   b) **Contour Map**

Fig. 1 Three-dimensional plot of transitional probability kernel for electricity consumption and associated Contour map of transition probability kernel (all regions), Source: authors' calculation.

Figure 2 displays the national evolution trend of electricity consumption patterns. There is a general convergence of electricity consumption per capita as indicated by the ergodic distribution in Figure 2a. However, province with average electricity consumption at 67-95 % of the national average could become lower and will be away from the average, which should be given special attention if the policy is to promote equal consumption across provinces. The overall trend of electricity consumption on the national scale is to diverge and decline. In the early period, those consume 66% to 94% of national average will decline. In the future, regions will become diverged in some cases but in most other cases, convergence is expected. Regions consuming 95% to 1.11 times of national average could further increase its electricity consumption, leading to further divergence. However, for those consuming more than 1.12 times of national average, their future electricity consumption tends to decline.
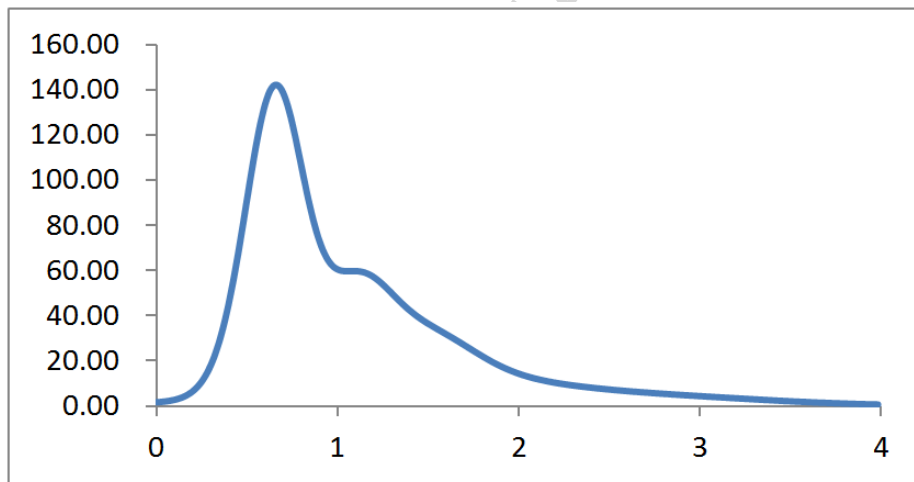
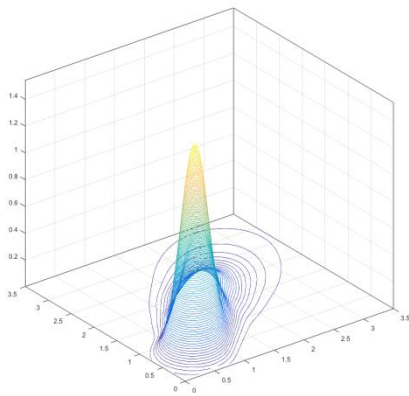a)   **Ergodic distribution of electricity consumption (all regions)**
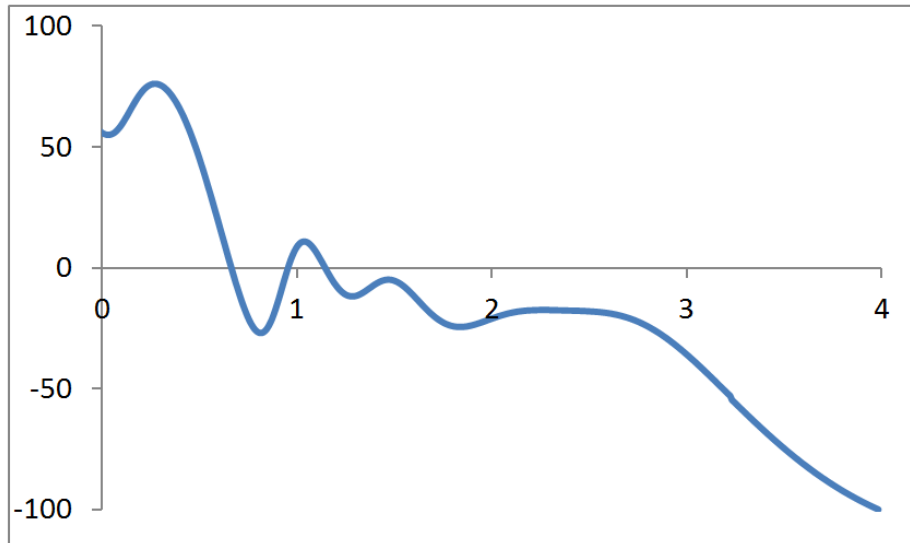
b) **Mobility probability plot of electricity consumption (all regions)**

Fig. 2 Ergodic distribution and Mobility probability plot of electricity consumption (all regions), Source: authors' calculation
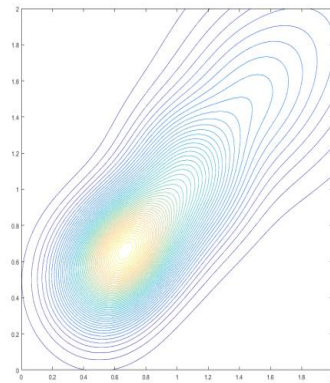
5.2   Overtime Pattern

To further explore whether the change of national electricity consumption pattern, Figure 3 summarizes the three-dimensional plots of electricity consumption together with their associated contour maps for three periods: 2000-2005, 2006-2010, and 2011-2015. The majority of provinces have peak consumption at 0.68 for the period 2000-2005, peak consumption at 0.67 for the period 2006-2010, and peak consumption at 0.66 for the period 2011-2015.

While for the majority of regions it is almost time invariant for their convergence clubs, there are differences in the minority of provinces. For the period 2000-2005, the minority of regions' consumption peak is at 1.67. For the period 2006-2010, the minority of regions' consumption peak declines to 1.36. For the period 2011-2015, the minority of regions' consumption peak further declines to 1.14. Such changing patterns indicate that at least some provinces have lowered their electricity consumption over time. We will explore which regions contribute to such change in the regional disparity section that follows.
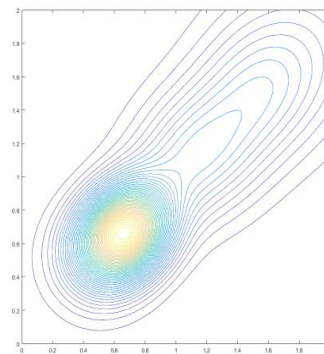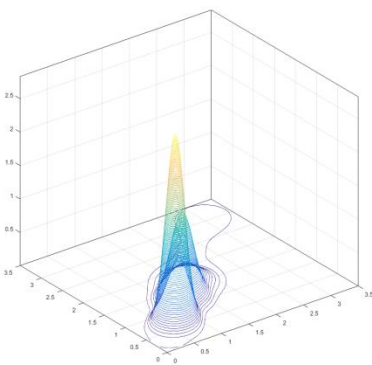
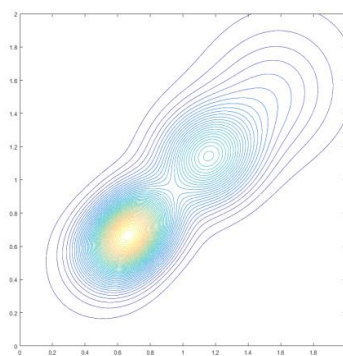a) Three Dimension Plot (2000-2005) b) Contour Map (2000-2005)
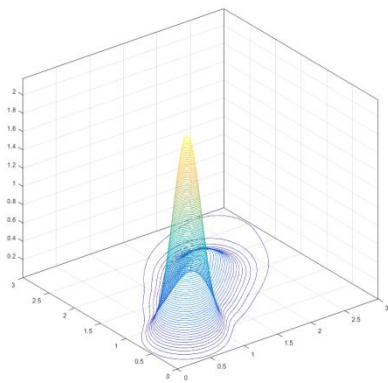
c) Three Dimension Plot (2006-2010) d) Contour Map (2006-2010)

e) Three Dimension Plot (2011-2015) f) Contour Map (2011-2015)

Fig. 3 Three-dimensional plot of transitional probability kernel for electricity consumption and associated contour map of transition probability kernel (all regions in different periods), Source: authors' calculation.
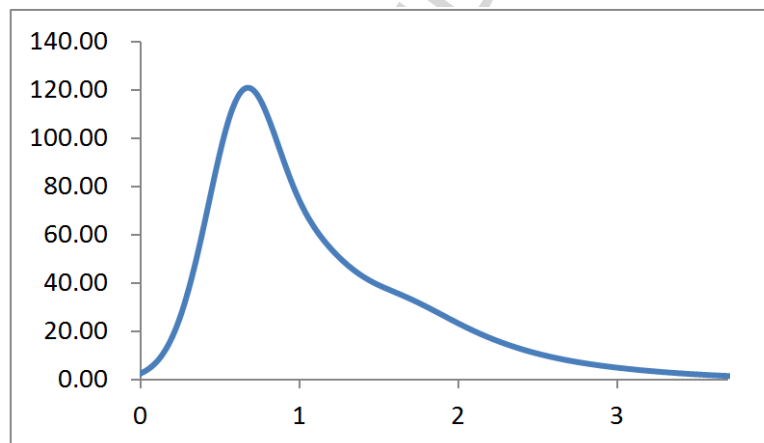
The ergodic distribution and mobility probability plot of electricity consumption for different periods are displayed in Figure 4, which provide detailed dynamics about

the future distribution of electricity consumption over time. For the period 2000-2005, Figure 4a and Figure 4b suggest that if the current period consumption is larger than 1.5 times of the average, then in the next period it tends to decline. However, if the current period consumption is less than 66%, it tends to increase in the next period. This is consistent with the findings in Figure 3 where from period 2000-2005 to period 2006-2010 only a minority of provinces consuming higher electricity will have a lower convergence club.

For the period 2006-2010, Figure 4c and Figure 4d suggest that if the current period consumption is lower than 67% or between 1.04 times and 1.32 times of the average, then it tends to continue increasing. Otherwise, there will be a decreasing consumption in the future period. The projection is echoed by Figure 3 where the minority of regions' convergence club decreased to 1.36 times in the period 2006-2010.

For the period 2011-2015, if the current period consumption is lower than 65% of, in between 94% and 1.13 times, or in between 2.11 times and 2.84 times, then in the next period it tends to increase the electricity consumption.

The analysis demonstrates that the electricity consumption of a majority of the regions will be around 60% of the national average. Moreover, convergence clubs can be observed and a small group of regions with electricity consumption a bit higher than the national average (about 110% of the national average) has emerged in the study period.
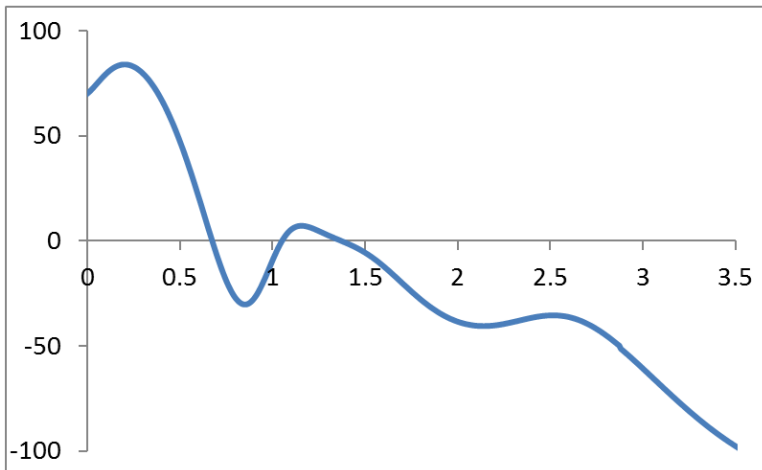

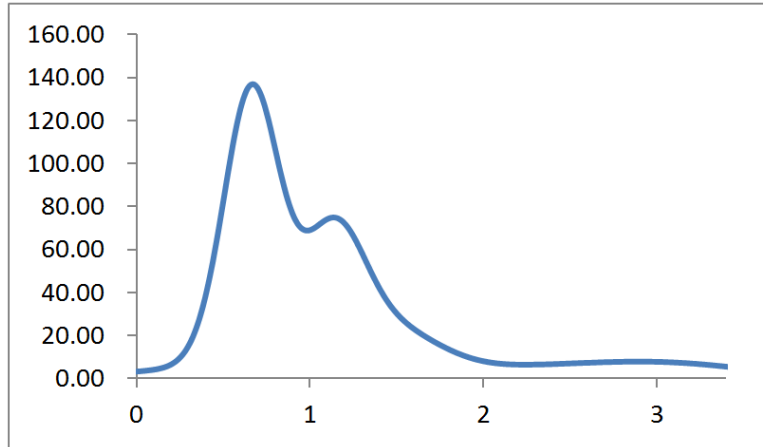a)   **Ergodic distribution of electricity consumption (2000-2005)**
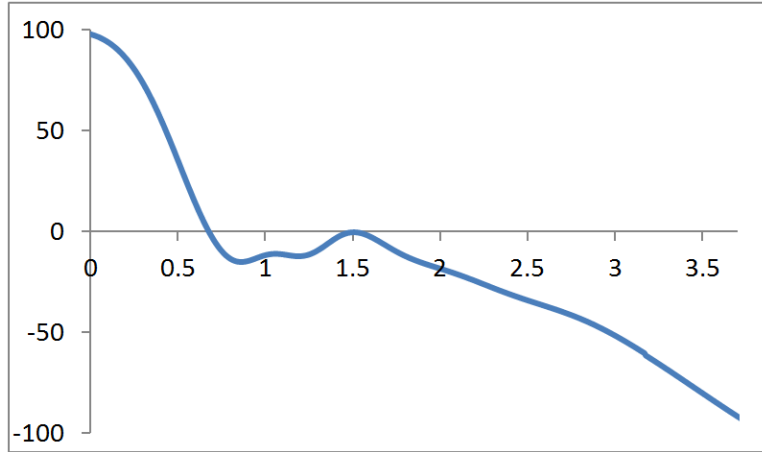
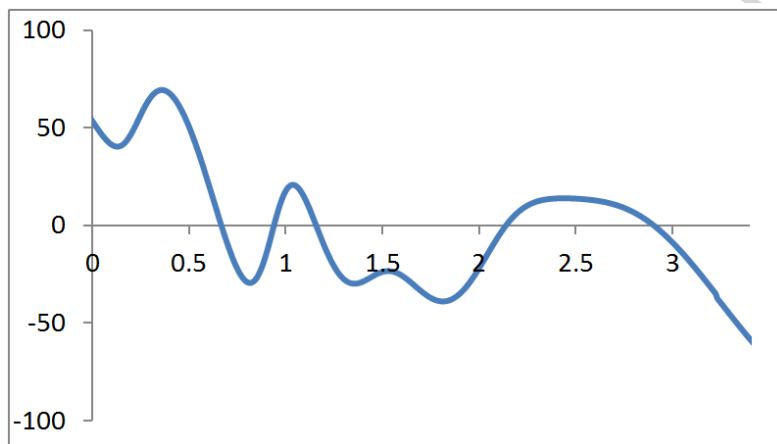b) **Mobility probability plot of electricity consumption (2000-2005)**
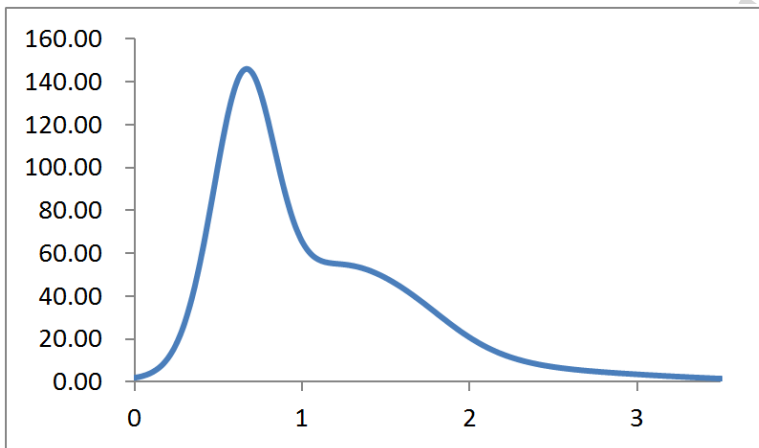
c) **Ergodic distribution of electricity consumption (2006-2010)**

d) **Mobility probability plot of electricity consumption (2006-2010)**

e)   Ergodic distribution of electricity consumption (2011-2015)

f) Mobility probability plot of electricity consumption (2011-2015)

Fig. 4 Ergodic distribution and Mobility probability plot of electricity consumption (all regions in different periods), Source: authors' calculation

5.3   Regional Disparity

We then explore the regional disparity of electricity consumption, with four sub-categories: eastern, central, western and north-eastern regions. The average value of RECPC in each region is shown in Table 3. It can be observed that the level of relative electricity consumption per capita dropped slightly for the eastern regions across the study period, whereas the central regions remained more or less the same. However, the western regions had a large increase in the relative electricity consumption, and the north-eastern regions registered a huge drop.

Table 3   Average Value of RECPC in Different Regions from 2000 to 2015

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
East	1.56	1.60	1.61	1.59	1.55	1.51	1.47	1.43	1.41	1.35	1.31	1.26	1.24	1.22	1.21	1.21
Central	0.75	0.75	0.74	0.74	0.73	0.74	0.74	0.76	0.75	0.75	0.74	0.75	0.75	0.75	0.73	0.71
West	1.04	1.01	1.01	1.02	1.07	1.06	1.11	1.13	1.06	1.08	1.14	1.23	1.26	1.31	1.36	1.34
North-East	1.25	1.19	1.11	1.07	1.02	0.95	0.90	0.87	0.87	0.86	0.84	0.82	0.80	0.77	0.76	0.74

A great disparity in the overall trend can be observed for the four regions, and it is thus of interest to understand the transitional dynamics of each region individually. Therefore, distribution dynamics analysis was conducted for each region one by one so as to provide detailed information on the evolution of the trend. Figure 5a shows the three-dimensional plots of electricity consumption in eastern regions, while Figure 5b displays the associated overhead view of the contour map. There are three peaks in Figure 5b, indicating that electricity consumption changes are clustered with three groups. Group 1 has a cluster around 0.6, Group 2 around 1.1 and Group 3 around 1.5, respectively.

To explore whether the three clusters of electricity consumption change vary converge in the future; ergodic distribution is adopted to estimate the distribution dynamics. Figure 5c shows the ergodic distribution which is the long run steady-state distribution of electricity consumption in eastern regions. Convergence clubs can be observed more apparently with two peaks, one around 1.1 and another around 1.5, and a less observable peak around 0.6. While thee ergodic distribution in Figure 5c has shown the emergence of convergence clubs, the mobility of regions cannot be known. In Figure 5d, the Mobility probability plot on distributions of the probability mass is below zero when the electricity consumption change is between 0.54 and 0.82, between 1.15 and 1.36, or above 1.57. Hence the good news is that when MPP ratios are larger than 1.15, future consumption in eastern regions generally tends to decline except for the ratios between 1.37 and 1.56. As eastern regions are more densely populated and substantially contribute to China's economic growth, more efficient energy consumption in the future may indicate an upgrading of the manufacturing sector and higher economic growth quality.
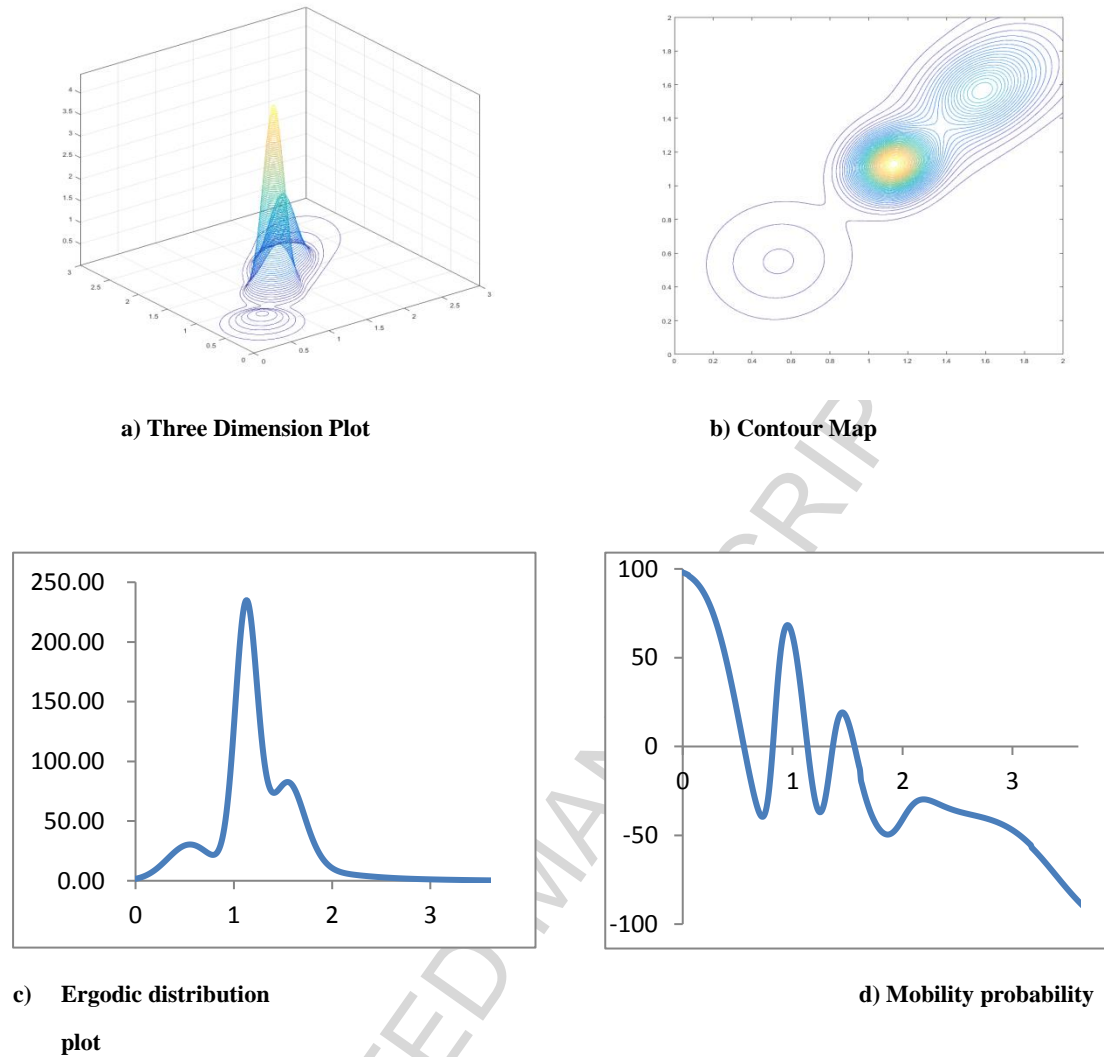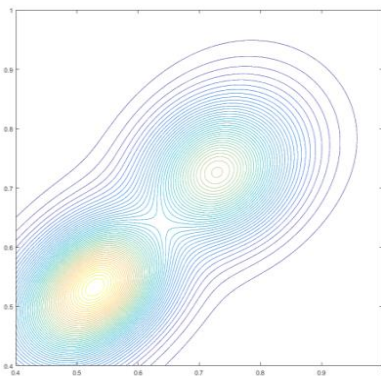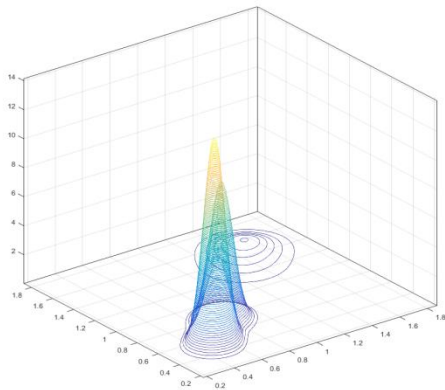
a) **Three Dimension Plot**

b) **Contour Map**

c) **Ergodic distribution plot**

d) **Mobility probability**

Fig. 5 Three-dimensional plot of transitional probability kernel, Contour map of transition probability kernel, Ergodic distribution and Mobility probability plot of electricity consumption (eastern regions), Source: authors' calculation.

As for central regions, Figure 6a displays their three-dimensional plots of electricity consumption change while Figure 6b displays the contour map. Similar to eastern regions, the width of the transition probability kernel for central regions are widely dispersed with the density mass concentrated along 45 degree diagonal line. There are two clusters in Figure 6b, around 0.55 and 0.75, both of which are below the national average. To forecast the long run distribution, Figure 6c shows the ergodic distribution of electricity consumption in central regions. Convergence clubs can be observed with twin peaks, both saliently observable, at 0.54 and 0.72.

Unlike eastern regions, the shape of MPP in central regions is less sophisticated. In Figure 6d, the MPP on distributions of the probability mass is above zero when the ratio is between 0.63 and 0.72, or between 0.98 and 1.41. The pattern is different

from eastern regions, as in central regions provinces with increasing electricity consumption tend to have higher probability of maintaining the use of more electricity in future periods. Unless the increase is more than 40%, there is no trend of lowering electricity consumption in the central regions. The results are actually more alarming than the eastern regions, indicating the difficulty of economic transition into greener development patterns in the central regions.

a)   **Three Dimension Plot**   b) **Contour Map**
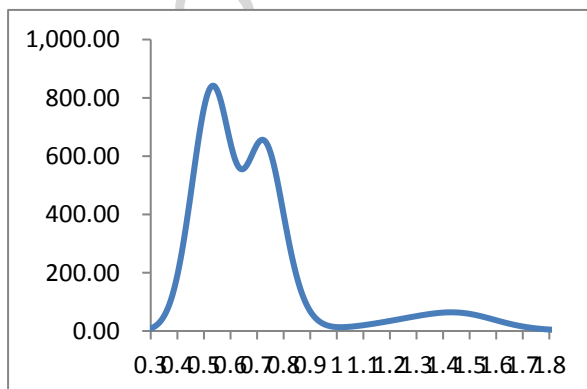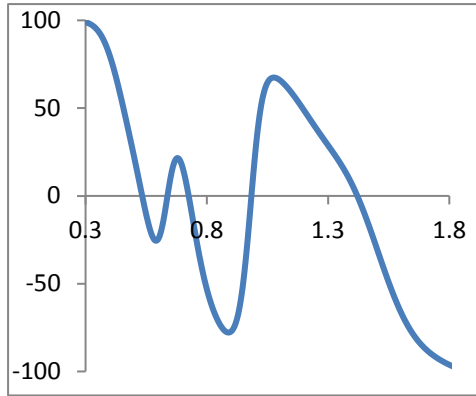
c) **Ergodic distribution**   d)
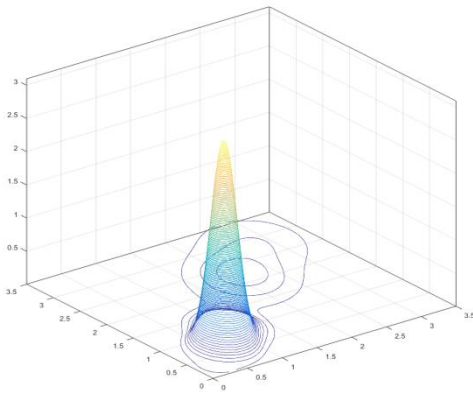
    Mobility probability plot

Fig. 6 Three-dimensional plot of transitional probability kernel, Contour map of transition probability kernel, Ergodic distribution and Mobility probability plot of electricity consumption (central regions), Source: authors' calculation.

Figure 7a displays the three-dimensional plots of electricity consumption in western regions, while Figure 7b shows the associated contour map. Similar to central regions, western regions have two convergence clubs, which peak around 0.7 and 2.3.The latter peak is not shown in Figure 7b, which does not necessarily mean it is less important but for composition aesthetics purpose of the figure. The width of the transition probability kernel for western regions are widely dispersed with the density mass concentrated along 45 degree diagonal line, indicating no significant difference from eastern and central regions regarding the persistence of future electricity consumption.

The ergodic distribution in Figure 7c clearly shows the second cluster of western regions' electricity consumption which is omitted in Figure 7b. Similar to eastern and central regions, the first peak of western region (below 1.0 for all regions, 0.72 for western region) tend to decrease in future periods as indicated by the Mobility Probability Plot. The probability mass is above zero when the electricity consumption ratio is between 1.39 and 2.22. Afterwards, it displays a net tendency to move downward in the next period for electricity consumption ratios above 2.22. Compared with eastern (1.56) and central regions (1.41), western regions have a much higher ratio (2.22) for the Mobility Probability Plot to turn negative. Such distinction suggests that electricity consumption patterns and trends in the western regions may be significantly different from eastern and central regions in the long-run: In the western regions, electricity consumption ratios may remain high and would not revert to decline in the long run unless they exceed 2.22. The distinct

pattern may reflect the rich resource in coal and good potential for electricity production in the western regions. Because the coal resources are in the western region but demand centers are in the eastern region, there are profound need to transfer coal or electricity from west to east (Shi, 2009; Shi et al., 2018). Transiting electricity from west to east is preferred to transporting coal for efficiency and environmental reasons and 'Transmission of electricity from the west to the east' (*Xi Dian Dong Song*) has been make national strategy since 2000s (Zhang, 22 Feb 2016). The literature has shown that most of China's least energy efficient provinces are in the west that depends on coal consumption due to resource abundance (Shi, 2007).
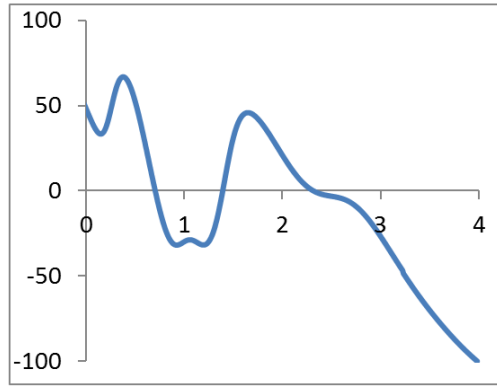

a)　　**Three Dimension Plot**　　　　　b)　　**Contour Map**
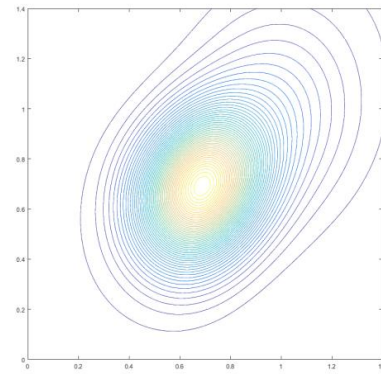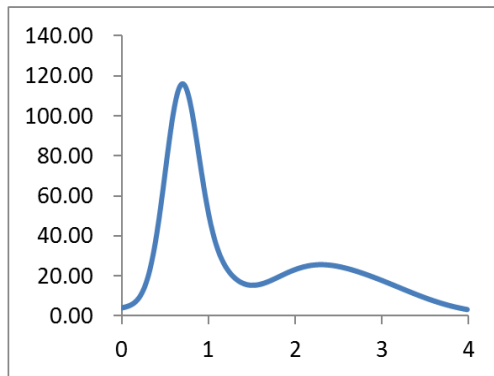
c)   **Ergodic distribution**   **d)**

Mobility probability plot

Fig. 7 Three-dimensional plot of transitional probability kernel, Contour map of transition probability kernel,

Ergodic distribution and Mobility probability plot of electricity consumption (western regions), Source: authors'

calculation.

Figure 8 shows the three-dimensional plots of the north-eastern regions. Similar to other regions, the width of the transition probability kernel for electricity consumption is dispersed with the density mass concentrated along 45 degree diagonal line. Compared with other regions, the plots of north-eastern regions are more widespread. This contrast indicates that electricity consumption of north-eastern regions is more volatile than other regions. The finding is reasonable as the north-eastern region is searching for new growth engine during the study period, the economic transition of which makes the electricity consumption pattern more dispersed.

Figure 8c displays the long run distribution of electricity consumption of north-eastern regions, with two convergence clubs at 0.66 and 1.19. The Mobility Probability Plot of north-eastern regions is more clear-cut in Figure 8d to forecast the future trend: MPP is above zero when the ratio is less than 0.66, but is below zero when the ratio exceeds 0.66. Basically there is a net tendency for electricity consumption to move downward in the coming periods, indicating that the north-eastern region is facing challenges in revitalizing old industrial areas.
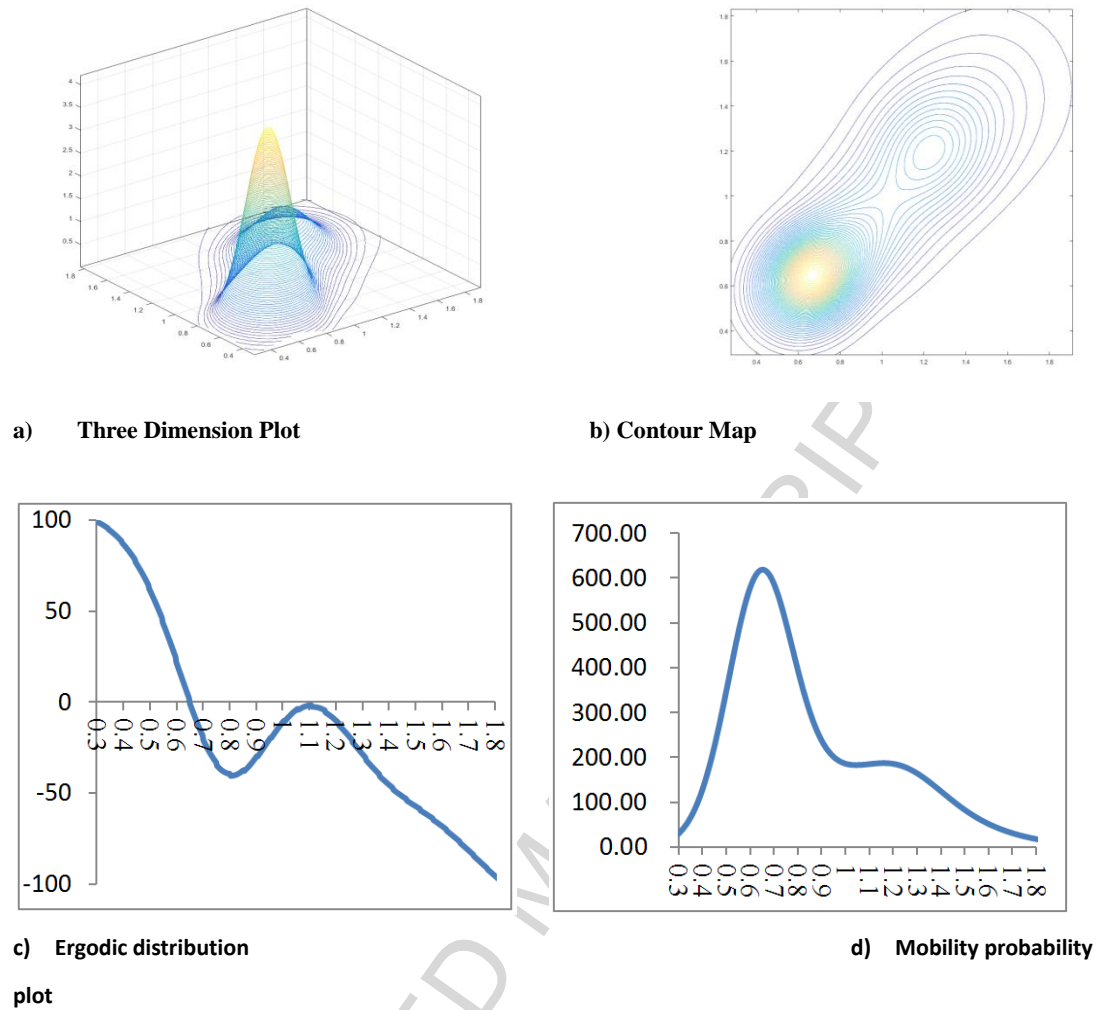
a)   **Three Dimension Plot**   b) **Contour Map**

c) **Ergodic distribution**   d)   **Mobility probability**

plot

Fig. 8 Three-dimensional plot of transitional probability kernel, Contour map of transition probability kernel, Ergodic distribution and Mobility probability plot of electricity consumption (north-eastern regions), Source: authors' calculation.

A comparison of ergodic distribution reveals that different regions have significantly unequal electricity consumption and such diversification tends to enlarge over time. Specifically, the national average convergence club is mostly clustered at 0.67. The eastern regions' convergence club is mostly clustered at 1.2, the central regions at 0.54, the western regions at 0.72, and the north-eastern regions at 0.66.

A comparison of Mobility probability plot in across regions demonstrates the different evolution patterns and future pathways of electricity consumption. The east region has more than national average electricity consumption and two of its peaks are larger than 1. However, the large variance in the MPP demonstrates that there is huge divergence among the province in the East regions. In the central region, all the two peaks are less than the national average, that is, there no province is close to the national average. In the western region, there is huge divergence between provinces:

two peaks are on opposition direction of the national average line. In the north-eastern region, the electricity consumption is persistent lower than the national average.

It can be observed that the electricity consumption level of the regions in the eastern zone is higher than the national average, while the consumption level of all the other regions are lower than the national average. It suggests that economic development and resource endowment could be the key factors that affect the steady state demand of electricity, with the economic development factor (in the east case) being more important in the resource endowment factor (in the west case).

5.4   Climate Impact

What has caused the salient regional disparity of electricity consumption patterns? We try to observe the impact of temperature by dividing the country into hot and cold areas, measured by whether the provincial capital's temperature is higher or lower than the national average. Figure 9 displays the three dimensional plot and associated contour maps for hot and cold regions. It shows the disparity in the hot regions as the eastern provinces in the hot region consume a lot of electricity and the non-eastern provinces in the hot region consume much lower than the national
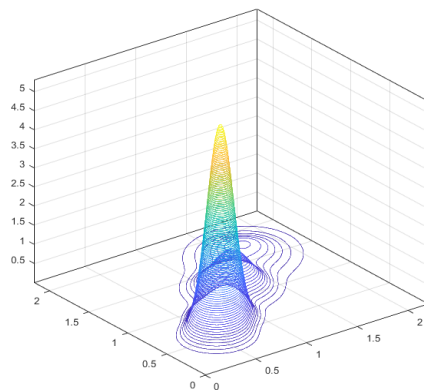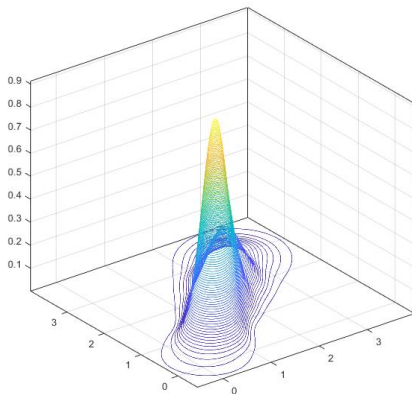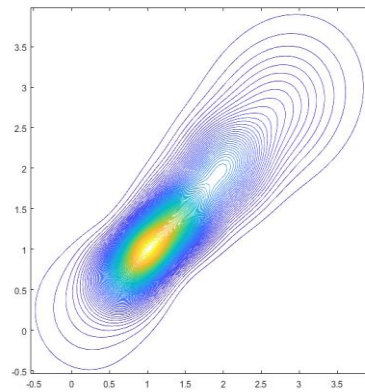

average.
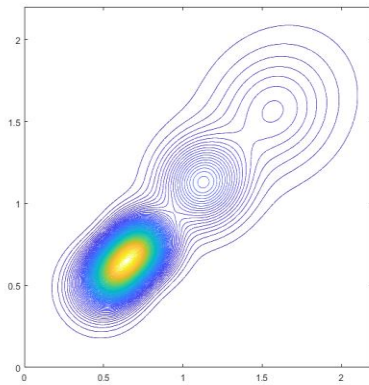
a)   **Three Dimension Plot of hot regions**   b) **Contour Map of hot regions**

c)   **Three Dimension Plot of cold regions**   d) **Contour Map of cold regions**

Fig. 9 Three-dimensional plot of transitional probability kernel for electricity consumption and associated Contour map of transition probability kernel (by hot and cold regions), Source: authors' calculation.

The future distribution dynamics can reveal if the electricity consumption will be affected by average temperature of each province. From the ergodic distribution in Figure 10, it shows that the convergence to the mean can be achieved by the cold regions, while the convergence to the mean cannot be achieved by the hot regions. The figure reveals that the majority of the provinces in cold regions have a level of consumption equal to the national average, while the provinces in the hot regions have three convergence clubs. The MPP shows that the hot regions with consumption level lower than 65%, 93-114%, 139-152% of the national mean will increase their consumption in the future, and so it leads to the emergence of three convergence clubs. The results highlight the complication within the hot regions. Actually, it suggests the disparity amongst the hot regions may be due to some factors unrelated to latitude (which is a major factor of temperature). The difference

between cold and hot regions could due to difference in energy use patterns for the residential and building sectors: in the cold regions, their primary need is heating provided by coal while in the hot region, their primary need is air conditioning provided by electricity. The different clubs in the hot regions may be due to industrial activities, which is quite diverse among the hot regions. The existence of the low consumption level convergence club in hot regions could be also due to the presence of provinces with lower level of urbanization since urban areas consumes much more than rural areas.
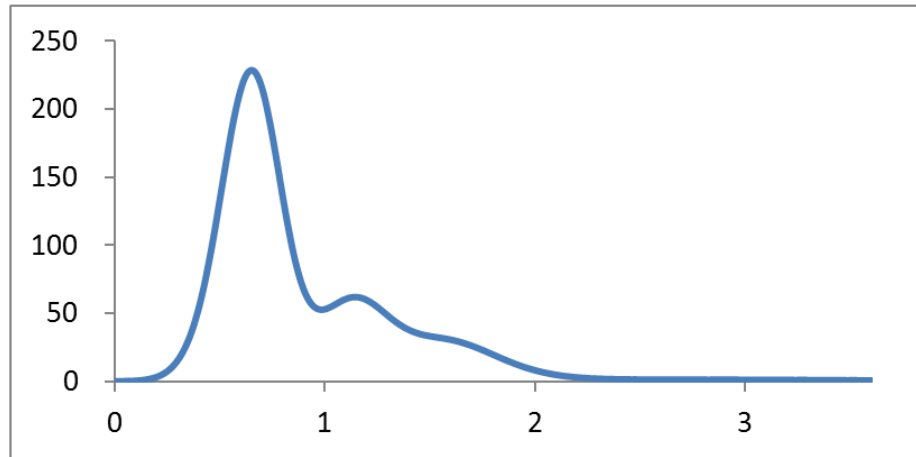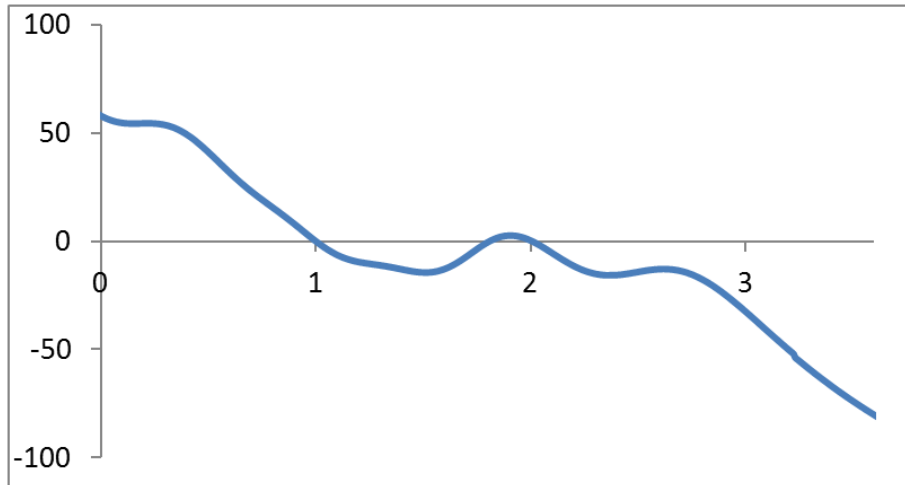

a)   Ergodic distribution of hot region
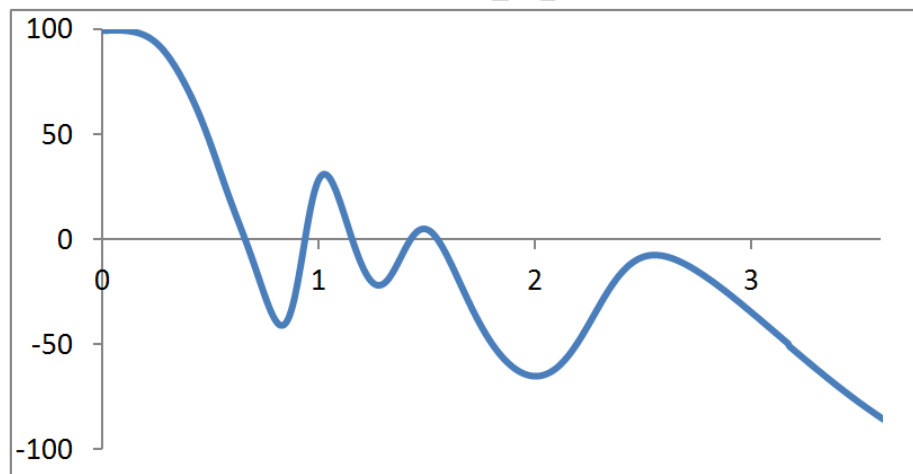
b)   Mobility probability plot of hot region
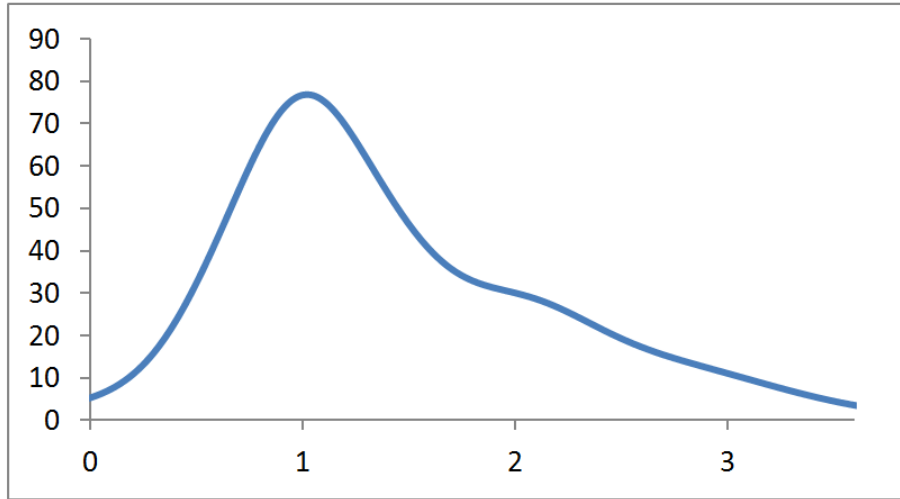
c) **Ergodic distribution of cold region**

d) **Mobility probability plot of cold region**

Fig. 10 Ergodic distribution and Mobility probability plot of electricity consumption (by hot and cold regions), Source: authors' calculation

6. Conclusion

The aim of this study is to examine regional disparity in electricity consumption in China. The analysis is based on a panel database which is compiled at the provincial level between 2000 and 2015. Distributional dynamics approach is then employed to reveal the trend and movement of each province within the distributions in different regional groupings. The results demonstrate significant divergence presents across provinces, over time, within different regional groupings and between different

climate zones.

Considerable significant divergence of per capita electricity consumption can be observed across provinces, regions, over time and different climate zones. Based on regional analysis, it is found that the eastern and non-eastern regions have huge disparity in electricity consumption. It reflects that the inequality of electricity consumption may stem from the inequality in regional income. While the north-eastern provinces are heavily-industrialized, the peak of the ergodic distribution of the north eastern region is also below the national average, which further supports the above argument that the main driving force of inequality in electricity consumption is correlated with the inequality in consumption.

The analysis across time suggests the emergence of convergence clubs in the future, thereby suggesting the change in the underlying trend of the distribution dynamics. The comparison between the hot and cold regions also pinpoints the emergence clubs for the hot regions, which could be due to difference in industry activities and urbanization that are diverse.

Our findings suggest that special policy attention is required for those regions displaying divergent consumption patterns. As argued in the literature (Herrerias and Liu, 2013), this divergence may imply there are barriers for energy-related technology diffusion and thus energy saving policy intervention is needed to improve the overall efficiency of the Chinese economy. However, the heterogeneity across provinces suggests that a uniform policy or regulation will not be effective, a conclusion that is also made by Fallahi and Voia (2015). Our study also suggests that intra-China interconnection needs to be strengthened. The electricity connectivity may lower the unequal electricity consumption across regions by providing better access to clean and affordable energy to all.

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Highlights:

- This study examines regional disparity in electricity consumption in China based on a panel database which is compiled at the provincial level between 2000 and 2015.
- Based on regional analysis, it is found that the eastern and non-eastern regions have huge disparity in electricity consumption, which reflects that the inequality of electricity consumption may stem from the inequality in regional income.
- While the north-eastern provinces are heavily-industrialized, the peak of the ergodic distribution of the north eastern region is also below the national average.
- The comparison between the hot and cold regions also pinpoints the emergence clubs for the hot regions, which could be due to difference in industry activities and urbanization that are diverse.
- Our findings suggest that special policy attention is required for those regions displaying divergent consumption patterns, and intra-China interconnection needs to be strengthened.