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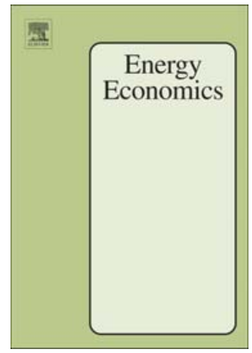

Residential energy consumption: a convergence analysis across Chinese regions

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Residential Energy Consumption:

A Convergence Analysis across Chinese regions

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Abstract

The process of urbanization and the raise of living standards in China have led an increasing trend in the patterns of residential consumption. Projections for the population growth rate in urban areas do not paint a very optimistic picture for energy conservation policies. In addition, the concentration of economic activities around coastal areas calls for new prospects to be formulated for energy policy. In this context, the objective of this paper is twofold. First, we analyse the effect of the urbanization process of the Chinese economy in terms of the long-run patterns of residential energy consumption at national level. By using the concept of club convergence, we examine whether electricity and coal consumption in rural and urban areas converge to the same long-run equilibrium or whether in fact they diverge. Second, the impact of the regional concentration of the economic activity on energy consumption patterns is also assessed by source of energy across Chinese regions from 1995 to 2011. Our results suggest that the process of urbanization has led to coal being replaced by electricity in urban residential energy consumption. In rural areas, the evidence is mixed. The club convergence analysis confirms that rural and urban residential energy consumption converge to different steady-states. At the regional level, we also confirm the effect of the regional concentration of economic activity on residential energy consumption. The existence of these regional clusters converging to different equilibrium levels is indicative of the need of regional-tailored set of energy policies in China.

Key Words: club convergence, transition paths, Chinese regions, residential energy consumption.
JEL Classification: C20, O18, O40, R11.
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1 Introduction

Convergence refers to the reduction of the disparities between countries or regions. In economic growth and environment literature this aspect has been the focus of a large body of empirical research,as an assumption of convergence lies behind any economic or environmental policy (Islam,2003; Herrerias, 2013). In contrast, convergence has received less attention in the energy economics literature despite the important implications for energy policy. Previous works on this area have focused on the analysis of convergence in different indicators used for energy policy such as energy efficiency, energy consumption and carbon dioxide emissions (Jakob et al, 2012; Mohammadi and Ram, 2012; Herrerias and Liu, 2013; Herrerias, 2013). To the best of our knowledge, this paper provides a first insight on the convergence patterns related to per capita residential energy consumption in urban and rural Chinese areas on the one hand, and across Chinese regions on the other.This paper aims to fill the gap in the existing literature by analysing the effect of urbanization and regional economic concentration on residential energy consumption in China.

In China, the growing trend in residential energy consumption is a relatively recent phenomenon. While energy consumption is still dominated by the industrial sector and more specifically by heavy industry as the most energy intensive industries[1], the rapid industrialization and urbanization process has resulted in an average growth in residential energy consumption of eight percent over the last two decades. Considering the demand of electricity, the figure rose by 12.35 per cent in 2012 (Zheng et al, 2014). Projections of this demand do not paint a very optimistic picture for energy conservation policy. In 2013, 46.3 per cent of the population lived in rural areas and this figure continues to fall, while the forecast for the urban population living in cities is around 60

[1] In 2009, eight industries in China consumed 72.5% of the national total: non-metallic mineral products,petroleum, coking and nuclear fuel processing, paper and paper products, ferrous metals, metal products, textiles,non-ferrous metals, and chemical products (see further details in Yao and Luo, 2014)

per cent by 2020 (Zhao, 2012). Among the relevant factors that can explain this expected strong demand for energy, three in particular are worth highlighting: China's economic development, the improvement of standard of living and the National Urbanization Plan.

The exceptionally steady and rapid growth of the Chinese economy has been based on two main factors: capital accumulation and export orientation policy over the last three decades (Herrerias and Orts, 2010). However, it has been argued that one of the main flaws of this growth model is the weak internal demand that hinders the achievement of sustainable development. The new urbanization plan may be one option for strengthening this aspect and encouraging household consumption.While there is no doubt that economic development has significantly improved people's living standards by raising per capita income, and therefore changing consumers' preferences, the new challenge for the Chinese economy is to balance the ambition of the urbanization process with energy programmes to achieve a low carbon economy. Continuous price reforms, deregulation of energy sector, energy efficiency policies and Chinese citizen's awareness of a green economy may curtail the growth rate of residential energy consumption. However, the effectiveness of such policies may have limited effects if the paths of growth differ across regions in China. Understanding the regional differences and analysing the possible existence of groups among Chinese regions can help to design specific energy programmes targeting each identified club.

In contrast to Herrerias and Liu (2013), we contribute to the existing literature by analysing the effects of Chinese urbanization and regional economic concentration on residential energy consumption patterns. To examine the effects of urbanization, we use a cluster analysis to test for convergence or divergence in the residential consumption of coal and electricity in rural and urban areas, whereas for the impact of regional economic concentration we test for convergence or divergence in the residential consumption of coal, electricity and liquid gas across Chinese regions over the period 1995-2011. By using the *log t* test proposed by Phillips and Sul (2007), we test the convergence behaviour across regions and examine whether club convergence is present in the data-generating process for the different sources of energy considered in this paper. This approach offers a number of interesting features when dealing with Chinese data. First, we endogenously determined the number of groups of regions as well as the provinces that belong to each club.Second, we consider explicitly the heterogeneity of our data generating process across regions and also over time. This aspect is assigned considerable importance due to the significant changes relating to China's energy reform and path of economic development which led to the well-known unbalanced growth among Chinese regions. Finally, we estimate the transition growth paths of energy consumption and their evolution over time. Findings from this research would be of great interest not only to academics but also to policy-makers as the very existence of clubs may indicate that a common energy policy cannot be effective; if different groups of regions show different convergence patterns it would be very challenging to design energy programmes for each identified club.Our results suggest the existence of club convergence for both urban and rural data at national level as well as residential energy consumption at regional level. First, we found that rural and urban areas display different convergence patterns depending on the source of residential energy consumption considered. Economic reforms initiated at the end of the 70s, rapid industrialization and, more recently, urbanization can explain these findings. Second, once the economic geography is explicitly considered in the analysis for each of the three sources of residential energy consumption examined, we found that there are four convergence clubs in the case of coal and two for both electricity and liquid gas. Divergence was not found in any of the cases. The results do not allow much room for optimism, since, looking at the transition paths of residential energy consumption,a growing trend is observed at those clubs with a significant number of provinces. The rapid urbanization process to promote internal demand in the Chinese economy should work in coordination with energy and environmental programmes, which in turn should target specific regions according to the identified club.

The rest of the paper is organised as follows. Section 2 reports an overview of the different notions of convergence in the empirical literature. Data and Methodology are described in Section 3. Results are presented in Section 4, while we draw our conclusions in Section 5.

2 Literature Review

Economic reforms initiated at the end of the 70s in China led to fast economic growth over the last three decades. However, it has been argued in the literature that, as a result of the creation of special economic zones, which encouraged the entry of multinationals in these regions with fiscal stimulus created unbalanced growth between coastal and non-coastal areas. This scenario is not so different from most other countries as the economic activity is concentrated in coastal areas for trading purposes with other countries. Economic prosperity, the relaxation of the Hukou system, and the pursuit of better standards of living push Chinese citizens to move from rural to urban areas. In 1978, 82.1% of population lived in rural areas, while only 17.9% lived in urban ones. These figures are in sharp contrast with the ones in 2013, when 46.3% of the population was living in rural areas and 53.7% in urban areas. Not only has the urban population, but the degree of urbanization is not homogeneous across regions, making it even more challenging to set economic policies in China. Considering recent data on urbanization for 2013, the provinces of Beijing (86.30%)[2], Tianjin (82.01%), Shanghai (89.60%), Liaoning (66.45%), Jiangsu (64.11%), Zhejiang (64%) and Guangdong (67.76%) show the highest rates of urbanization compared with regions like Guangxi (44.81%), Yunnan (40.48%), Gansu (40.13%) and Tibet (23.71%), which show the lowest rates. If we take into account the population density of urban areas in 2013, the provinces of

[2]Share of urban population over total population shown in brackets.

Heilongjiang[3] (4922), Shanghai (3809), Jiangxi (4542), Henan (4982) and Shaanxi (5541) appear in the top positions, while regions such as Ningxia (1253), Tibet (1820), Chongqing (1847), Guangxi (1543) and Inner Mongolia (1059) show the lowest levels of urban population density. The Chinese government is encouraging these trends by means of the National Urbanization Plan, although it also aims to promote inland regions by relocating industry to those areas address the well-known unbalanced growth. The projections of these urbanization and industrialization trends may suggest that residential consumption will tend to increase and therefore active prospects for energy policy will be required.

This paper applied methods primarily developed in the economic growth literature to test for convergence. Islam (2003) provides a detailed description of the different concepts of economic convergence and surveys the existing methods of testing for its presence. In the area of energy economics, as pointed out by Kim (2015), per capita electricity consumption may be a better indication of the nature of standard of living than income. The analysis of the relationship linking energy consumption and income has prompted a large body of empirical research (See Herrerias and Joyeux, 2014) that has nevertheless produced conflicting results on the direction of the causality between these two macro-magnitudes. Such research has been useful for the design of energy policies across countries and regions, however the explicit assumption behind these studies is that countries and regions converge at the same path. This hypothesis of convergence has, however, received less attention in the empirical literature.

Empirical studies usually examine energy consumption and energy intensity convergence using data on countries at aggregate level. Nielsson (1993) and Goldemberg (1996) observed convergence in energy intensity levels both in developing and developed economies between 1950 and 1988. Markandya et al. (2006) estimate convergence in energy intensity in the transition economies

[3]Density measure in persons per square kilometre shown in brackets.

of Eastern Europe and in the then members of the EU. Le Pen and Sévi (2010) study energy intensity stochastic convergence using Pesaran's (2007) method in a set of 97 countries over the period 1971-2003. They reject global convergence hypothesis but find some signs of convergence for Middle-East, OECD and Europe sub-groups. Liddle (2010) analyses two large data sets of countries all around the world. They find convergence for groups of developed economies and non-convergence or divergence for developing ones. These authors use four different measures of convergence: β*-convergence*, two σ*-convergence* and λ*-convergence*. Duro and Padilla (2011) find convergence in energy consumption for OECD countries but not for other regions. Ezcurra (2007) used a non-parametric approach in data of 98 countries between 1971 and 2001 to conclude that the convergence achieved in energy intensity was mainly due to the evolution of those countries located at both ends of the distribution at the beginning of the period.

Another strand of empirical literature on convergence analyses per capita use of electricity. Maza and Villaverde (2008) focus on the residential component and analyse σ and β*- convergence* and apply non parametric techniques to a sample of 98 countries. They find a weak process of convergence caused by the rapid economic changes in developing economies and by policies implemented in developed countries. Mohammadi and Ram (2012) work with total electricity and energy usage. They analyse a large country data set covering the period 1971-2007 and conclude, among other results, that convergence in electricity usage is stronger than in energy consumption. In a recent paper, Kim (2015) makes use of *log t* test proposed by Phillips and Sul (2007) to identify convergence clubs for a set of 109 countries during the period 1971-2009. Overall convergence is rejected for per capita electricity consumption. They also found that relative convergence does not hold for any regional groups, thus concluding that regional divergence does not drive the divergence in per capita electricity consumption. Finally, considering the existing literature on energy convergence in the case of China, Herrerias and Liu (2013) analyse the stochastic electricity-intensity convergence across Chinese provinces from 2003 to 2009 using monthly data. They perform several unit root tests that report that thresholds effects exist as well as *club convergence*.

To sum up, analysing the convergence behaviour of per capita residential consumption across Chinese regions and whether such convergence process occurs within a group of regions may help to inform suitable energy programmes aimed at achieving a sustainable growth model based on the green economy.

3 Data and Methodology

3.1 Data Description

In order to test the club convergence hypothesis, we use two different data set both of which over the period 1995-2011. Firstly, we investigate similarities in rural and urban coal and electricity per capita consumption with national data sourced from the *China Energy Databook v.8.0, September 2013*, during the period considered[4]. This information is summarized in figure 2. We take advantage of the monotonically increasing urban share from 1995 to 2011 in China to construct the figure. We observe a slight divergence in consumption by source of energy considered from 1996, at least in absolute terms, so empirical analysis will determine whether or not there is convergence. Convergence by area (rural or urban) is more difficult to analyse at first glance.

Secondly, we use data on residential energy consumption for 29 Chinese regions sourced from the *China Energy Databook v.8.0, September 2013*, to investigate whether differences in coal, electricity and liquid petroleum gas diminish over time. We collect annual data on these three sources for Chinese provinces as listed in table 1.[5] In this table, we group provinces in eastern, central and

[4]There is no data available on urban and rural liquid gas consumption

[5]The Chinese statistics do not report data for Ningxia and Tibet regions for all sources of residential consumption.

western regions and show their population for the years 1995, 2008 and 2011 as well as their growth rate. The eastern provinces (comprising the largest population share) are the ones with the higher growth rate, particularly in the last years of the period under study. Shanghai (3.8%), Beijing (3.0%), Tianjin (2.6%) and Guangdong (2.2%) experienced the highest annual growth rates from 1995, with an specially dramatic that surge in the last years in Shanghai (19.1%) and Tianjin (11.8%). There was little population growth in the central provinces, and it was even negative for several provinces in the period 2008-2011: Hubei (-2.0%), Hunan (-1.2%), Anhui (-4.0%) and Henan (-1.8%). Finally, in regard to the western region, growth was also low and even negative for some provinces.

Table 2 collects information on coal, electricity and liquid petroleum gas consumption per capita for all provinces and means for eastern, western and central regions. For the sake of simplicity, we report 1995, 2008 and 2011 data and the annual growth rate between those years. This information is complemented by figure 1, where the Chinese provinces are coloured according to per capita consumption delimited in function of the 25th, 50th and 75th percentile per capita consumption of each energy source.

At national level, per capita consumption of coal experienced an overall decline of -1.2% over the whole period (1995-2011), although in the latest years of the sample (2008-2011) there is a sharp change in this trend with an annual increase of 7.2%. A similar but more marked pattern is observed for western provinces, where the decline for the whole period was -2.5% whereas the period 2008-2011 exhibits an increase in per capita coal consumption of 9.9%. Similarly, central provinces experienced a modest increase of 0.3% for the whole period and a strong increase of 8.7%

Similarly, in the case of coal, Hainan province does not have data and Chongqing, Sichuan and Yunnan in case of liquid petroleum gas. Chongqing and Sichuan and Gunagdong and Hainan are treated in these statistics as separated regions.

in the last years. Eastern provinces are the ones with a clear (and constant) fall in the period (-6.0%). Figure 1 suggests that coastal areas have less intensive coal consumption than inland ones and that this pattern holds over time.

The case of electricity is quite different. At national level, per capita electricity consumption increased by 10.3% over the entire period (1995-2011), with the mean increment being higher in the first years than in the last years of the sample (10.6% and 8.8% respectively). This pattern is especially marked for eastern provinces, with Shanghai being the only Chinese province experiencing a notable decline in per capita electricity consumption in the period 2008-2011. However, as suggested by figure 1, in 2011 electricity consumption is still the predominant energy source among coastal (eastern) provinces. Central and western provinces have a higher mean annual growth rate in the last years of the sample (2008-2011).

Finally, we analyse the case of liquid petroleum gas. At national level, there is a declining trend in the annual growth rate (6.2% in 1995-2008 compared with 2.4% in 2008-2011). This pattern can be observed in the mean for the eastern area. However, there are important differences among provinces: while Shanghai, Jiangsu and Fujian experienced an important decline in the period 2008-2011, exactly the opposite pattern is observed for Liaoning and Hebei. The central area, by contrast, shows an increase in consumption during the latest years (2008-2011), driven by the huge rise in provinces such Inner Mongolia (36.6%), Henan (36.1%) or Jilin (43.2%). For the western region, information is scarce and the pattern observed is not clear. Figure 1 confirms this lack of empirical regularity.

3.2 Methodology

The panel data model by Phillips and Sul (2007) has been proposed to represent the behaviour of economies in transition allowing for different convergence paths with heterogeneous individuals.

Heterogeneity is formulated as a nonlinear time varying factor model which provides flexibility in idiosyncratic behaviour over time and across sections. The model allows for idiosyncratic behaviour and also retains some commonality across the panel meaning that when the heterogeneous time varying idiosyncratic components converge over time to a constant, panel convergence holds. The starting point of the test is a simple factor model:

$$X_{it} = \delta_i \mu_t + \epsilon_{it} \tag{1}$$

where δ_i measures the idiosyncratic distance between some common factor μ_t and the systematic part of X_{it}. This model seeks to capture the evolution on the individual X_{it} in relation to μ_t by means of its two idiosyncratic elements, that is, the systematic element δ_i and the error ϵ_{it}. Phillips and Sul (2007) modified this initial model by allowing the systematic idiosyncratic element to evolve over time, thereby accommodating heterogeneous agent behaviour and the evolution in that behaviour by means of a time-varying factor-loading coefficient δ_{it}. Furthermore, they allow δ_{it} to have a random component, which absorbs ϵ_{it} in equation (1) and allows for possible convergence behaviour in δ_{it} over time in relation to the common factor μ_t. The new model has the following time-varying representation:

$$X_{it} = \delta_{it} \mu_t \tag{2}$$

The time varying behaviour of δ_{it} is modeled in a semi-perametric form as follows:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \tag{3}$$

where δ_i is fixed, $\sigma_i > 0$, ξ_{it} is i.i.d (0,1) across i but weakly dependent on t, and $L(t)$ is a slowly varying function for which $L(t)$ tends to infinity as t also goes to infinity. Following Phillips and

Sul (2007) the $L(t)$ function is assumed to be *logt*. ξ_{it} introduces time-varying and region-specific components to the model. The size of α determines the behaviour (convergence or divergence) of δ_{it}. This formulation ensures convergence of the parameter of interest for all $\alpha \geq 0$, which is the null hypothesis of interest since $\delta_{it} = \delta_i$ as $t \to \infty$. Furthermore, if this hypothesis holds and $\delta_i = \delta_j$ for $i \neq j$, the specification in (3) still allows for transitional periods in which $\delta_{it} \neq \delta_{jt}$, thereby incorporating the interesting possibility of transitional heterogeneity or even transitional divergence across i. Regional transition can be analized using the relative transition path, defined as:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \tag{4}$$

which measures the loading coefficient δ_{it} in relation to the panel. The variable h_{it} traces out an individual trajectory for each i relative to the panel average. So, h_{it} measures region i's relative departure from the common steady-state growth path μ_t. When there is a common limiting transition behaviour across regions, we have $h_{it} = h_t$ across i, and when there is ultimate growth convergence then $h_{it} \to 1$ for all i as $t \to \infty$.

The null hypothesis of convergence can be written as:

$$H_0 : \delta_{it} = \delta \text{ and } \alpha \geq 0 \tag{5}$$

and the alternative:

$$H_A : \delta_{it} = \delta \text{ for all i with } \alpha < 0 \tag{6}$$

or

$$H_A : \delta_{it} \neq \delta \text{ for some i with } \alpha \geq 0, \text{ or } \alpha \leq 0 \tag{7}$$

The alternative hypothesis includes divergence, as in (6) and (7), but can also consider club convergence. For example, if there are two convergent clubs, the alternative is:

$$H_A : \delta_{it} \rightarrow \begin{cases} \delta_1 \text{ and } \alpha \geq 0, \text{ if } i \in G_1 \\ \delta_2 \text{ and } \alpha \geq 0, \text{ if } i \in G_2 \end{cases} \tag{8}$$

where G stand for an specific club.

Phillips and Sul (2007) show that these hypotheses can be statistically tested by means of the following '*logt*' regression model:

$$log(H_1/H_t) - 2log(log(t)) = a + b\,log(t) + u_t \tag{9}$$

where $H_t = \frac{1}{N}\sum_{i=1}^{N}(\hat{h}_{it} - 1)^2$ measures the distance of the panel from the common limit, and t=[rT], [rT]+1,...,T with some r $>$ 0. Phillips and Sul (2007) suggest r=0.3 based on their simulation experiments.

The regression test of convergence in (9) is made up of three stages (Phillips and Sul, 2007, p.1788). In the first step, the cross-sectional variance (H_1/H_t) ratio is constructed, and then in the second step the conventional robust t statistic, $t\hat{b}$, for the coefficient $\hat{b}$ is computed using (9). Finally, in the third step, an autocorrelation and heteroskedasticity robust one-side t test of the inequality null hypothesis $\alpha \geq 0$ is applied using the estimated coefficient $\hat{b}$ and HAC standard errors. At the 5% percent level, the null hypothesis of convergence is rejected if the statistic has a value below -1.65.

However, the novel aspect of this approach is that convergence patterns within groups can be examined using *logt* regressions, that is, the existence of club convergence and then clustering. This fact is particularly relevant since the rejection of the null of convergence does not necessarily imply divergence, since different scenarios may be in place, such as separate points of equilibrium or steady-state growth paths, as well as convergence clusters and divergent regions in the full panel. The existence of club convergence raises an important concern, that is, how to identify the regions that belong to each cluster. In this regard, Phillips and Sul (2007) suggested the following method.

The convergence approach by Phillips and Sul (2007) presents clear advantages. First, it is a test for relative convergence as it measures convergence to some cross-sectional average, in contrast to the concept of level convergence presented by Bernard and Durlauf (1996). Second, this approach outperforms the standard panel unit root tests since in the latter case $X_{it} - X_{jt}$ may retain non-stationary characteristics even though the convergence condition holds, in other words, panel unit root test may classify the difference between gradually converging series as non-stationary. As a further problem, a mixture of stationary and non-stationary series in the panel may bias results. Moreover, test results are sometimes not particularly robust. In contrast, the Phillips and Sul (2007) test does not depend on particular assumptions concerning trend stationarity or stochastic non-stationarity of the variables to be tested.

4 Results

Results for testing club convergence are presented in Table 3, while the transition paths are reported in Figure 3. Table 3 shows the findings for urban and rural areas at national level (in the case of coal and electricity) and the results for coal, electricity and liquid gas respectively for the analyzed provinces. The transition path for rural and urban areas for coal and electricity is reported in Figure 3a, while the equivalent for coal, electricity and liquid gas consumption at regional level are shown in Figures 3b, 3c and 3d respectively.

Our empirical strategy starts by analysing per capita coal and electricity consumption for urban and rural areas at national level. In a second step, given the well-known heterogeneity of the Chinese provinces, we examine per capita residential consumption and we disaggregate the residential consumption into coal, electricity and liquid gas for each province to test the existence of club convergence.

Using data at national level on urban and rural energy consumption (coal and electricity), we find that there are two clubs. Our findings suggest that electricity and coal consumption are converging to their respectively clubs, independently of the geographical area considered (urban or rural). Looking at the transition paths (Figure 3a), we find evidence of a change in the energy mix from 1995 onwards. Specifically, coal was replaced by electricity in urban areas and from 1997 onwards electricity displays a steady pattern at high levels of consumption, while residential coal consumption shows a decreasing trend. In rural areas, coal shows a relatively constant pattern over the period considered, while as of 1997 electricity displays an increasing trend. One of the main factors responsible for the movement of the rural population into urban areas is the relaxation of the *Hukou* system (restrictions to the mobility of workers). Over the period under study in this paper, there were two main reforms, one in 1995 and other in 2005. The first one further relaxed restrictions on temporary migration by reducing the entry barriers in small cities and towns for the rural population. As these places were less attractive for rural workers seeking a job, most of the rural population preferred to move to urban areas (medium and large cities) without changing the *Hukou* status, which increased the gap between rural and urban populations. In 2005, restrictions on temporary migration were removed and some provinces allowed the entrance of permanent migrant workers in medium and large cities. Related to this, the National New-type Urbanization Plan (2014-2020) which aims to increase the weight of the internal demand by promoting the urbanization process in an environmental friendly way, can be considered as a factor that might explain the increase in residential consumption and the shift from coal to electricity at national level in China. Finally, the presence of multinationals in China since the 1990s has led a process of technology transfer via foreign direct investment and imports, thus raising the level of technology in the country. Most of this technology has improved Chinese citizens' standard of living but it has also required a significant amount of electricity consumption and probably partly explains the change in the observed energy mix.

Our findings in terms of residential coal consumption at regional level show the existence of four convergent clubs (Figure 4a). The first group of regions includes Beijing, Hebei, Inner Mongolia, Shanxi, Gansu, Qinghai, Guangxi, and Guizhou. The second club comprises Shandong, Heilongjiang, Jilin, Liaoning, Shaanxi, Xinjiang, Henan, Hubei, Hunan, Sichuan, Yunnan, and Chongqing. The third one contains regions like Anhui, Fujian, Jiangxi, Shanghai, Zhejiang and Tianjin, while the fourth contains Jiangsu and Guangdong. Looking at the transition paths, we observe distinctive behaviour of the first club compared to the others three clusters found. It shows an increasing trend especially from 2003 onwards. Regions that belong to the first group are the ones that also produce coal (see Herrerias and Girardin 2013). The transition path of the second club shows a steady pattern over the period under study with a slight decrease in residential coal consumption. This second club is mostly allocated in central China, where the hydropower is concentrated. Three regions in the north-east of China comprise a small cluster within this second group along with Xinjiang in the western part of China. Finally, in the south-east of China, there are two clubs (Club 3 and 4) with a relatively steady pattern and a decreasing trend. The regions in the south of China are characterized by the presence of multinationals that bring advanced technology to China, which facilitates the better use of energy resources through energy savings.

We find two clubs in residential electricity consumption (Figure 4b). The dominant one contains Anhui, Fujian, Jiangsu, Jiangxi, Shanghai, Zhejiang, Beijing, Hebei, Inner Mongolia, Shanxi, Qinghai, Shaanxi, Guangdong, Guangxi, Hainan, Henan, Hubei,Hunan, Guizhou, and Yunnan, while the smaller one comprises Shandong, Tianjin, Heilongjiang, Jilin, Liaoning, Gansu, Xinjiang, Sichuan, and Chongqing. The effects of the Asian crisis are evident in both groups of regions as residential electricity consumption sharply decreases in the transition paths. Two opposite trends are found after China's entry into the WTO. The dominant group shows higher levels of electricity consumption while the second group shows lower levels. However, both display steady pattern as of 2006 where energy and conservation policies where included in the Five-Year Plan. Higher levels of consumption are concentrated in regions in the south, centre and north of China. After China's entry into the WTO, the volume of trade grew significantly especially in those regions with a higher presence of multinationals. Such regions were attractive for the rural population in search of economic prosperity for their families, leading to an increase in the urbanization rate. Although urbanization can result in higher electricity consumption, better managerial skills in the use of technology, low-energy consumption technology and energy policies can curtail residential electricity consumption.

Finally, we examined residential liquid gas consumption. Our findings suggest the existence of two clubs (Figure 4c). The first group comprises the regions of Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Shanghai,Zhejiang, Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin, Heilongjiang, Jilin, Liaoning, Gansu, Guangdong, Guangxi,Hainan, Henan, Hubei, Hunan, and Guizhou, while the second contains the provinces of Qinghai, Shaanxi, and Xinjiang. Figure 3d shows the transition path for the two clusters identified. The dominant club displays a slightly increasing trend as of 2009, yet overall the trend is stable over the period under analysis. In contrast, the three regions that belong to the second group show a decreasing trend from 2000 onwards, probably as a consequence of a change in the energy mix, with liquid gas being substituted by electricity.

5 Conclusion

Since economic reforms in 1978, China has achieved significant economic development and has improved the standard of living of its citizens. The engine of the Chinese economy is no longer only manufacturing as it used to be in the past, but is gradually changing towards a new scenario as a result of a more modern economy. As with any other middle-income country, China is undergoing a rapid process of urbanization and industrialization, which has led to an increase in the levels of pollution and energy consumption. Although industry still consumes around 70% of total energy, residential energy consumption has gained in importance, with a clear increasing trend. This energy demand has resulted in serious environmental problems. Since 2006, China has become more aware of the environmental consequences and this is reflected in the Five-Year Plan with a set of energy and environmental conservation programmes. As a middle-income country, highly dependent on external demand, the Chinese economy aims to balance the sources of growth by promoting internal demand. However, the rapid process of urbanization is one of the challenges for energy conservation policies. The analysis of convergence is important in this context as it is the explicit assumption behind any energy-saving measure. Therefore, in this study we investigate the convergence behaviour of residential energy consumption in the Chinese economy.

The novel aspect of this paper relies in its analysis of the effect of urbanization process with respect to the long-term patterns of residential energy consumption in China. In addition, we investigate the existence of club convergence among Chinese regions in terms of residential energy consumption in the case of coal, electricity and liquid gas over the period 1995-2011. By using the concept of club convergence, which in turn is linked with the existence of multiple equilibria, we can take into account the heterogeneity of the Chinese provinces. The method proposed by Phillips and Sul (2007, 2009) is especially suitable for economies in transition like China. The time-varying property of the test allows us to take into account the significant transformation of this country over time. To the best of our knowledge, this is the first attempt in the empirical literature to analyse this aspect, and so it may offer useful insights for energy policy design in light of the urbanization process and the geographical concentration of economic activities.

Our results suggest that the energy mix has changed in urban areas as a result of the urbanization process. More specifically, coal has been replaced by electricity in these zones. The relaxation of the *Hukou* system and the New Urbanization Plan probably explain these findings. Our analysis at regional level reveals that Chinese regions converge into clubs, which is related with the existence of multiple equilibria. We find four clubs for coal, and two for both electricity and liquid gas. The existence of clubs indicates that common energy programmes might have a limited impact as regions are converging at different steady states. Regionally-specific energy policies need to be designed taking into consideration the convergence paths for energy source. Information coming from the transition paths also reveals the distinctive behaviour of each club, with coal and electricity consumption increasing in the major clusters. As China moves towards ever greater urbanization, more attention needs to be paid to reconciling the low carbon economy and green growth with the higher levels of residential energy consumption and environmental pollution.

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List of Tables and Figures

TABLE 1. Population per provinces and growth rate: 1995-2011

Province	Population (N) (10,000 habs.)				Pop. Growth Rate (%)		
	1995	2008	2011		95–08	08–11	95–11
EAST							
Shanghai	1,301	1,391	2,347		0.5	19.1	3.8
Beijing	1,251	1,695	2,019		2.4	6.0	3.0
Tianjin	895	969	1,355		0.6	11.8	2.6
Liaoning	4,034	4,315	4,383		0.5	0.5	0.5
Jiangsu	7,066	7,677	7,899		0.6	1.0	0.7
Zhejiang	4,389	5,120	5,463		1.2	2.2	1.4
Guangdong	7,387	9,544	10,505		2.0	3.2	2.2
Shandong	8,705	9,417	9,637		0.6	0.8	0.6
Fujian	3,237	3,604	3,720		0.8	1.1	0.9
Guangxi	4,543	4,816	4,645		0.4	-1.2	0.1
Hebei	6,437	6,989	7,241		0.6	1.2	0.7
Total	49,246	55,536	59,213	Mean	0.9	4.1	1.5
Mean	4,477	5,049	5,383	Median	0.6	1.2	0.9
Std.Dev	2,683	3,065	3,085	Std.Dev.	0.6	6.1	1.2
CENTRAL							
Heilongjiang	3,701	3,825	3,834		0.3	0.1	0.2
Jilin	2,551	2,711	2,749		0.5	0.5	0.5
Hubei	5,772	6,111	5,758		0.4	-2.0	0.0
Shanxi	3,077	3,411	3,593		0.8	1.8	1.0
Hunan	6,392	6,845	6,596		0.5	-1.2	0.2
Hainan	724	854	877		1.3	0.9	1.2
Anhui	6,000	6,741	5,968		0.9	-4.0	0.0
Jiangxi	4,063	4,400	4,488		0.6	0.7	0.6
Henan	9,100	9,918	9,388		0.7	-1.8	0.2
Inner Mongolia	2,284	2,414	2,482		0.4	0.9	0.5
Total	43,664	47,229	45,733	Mean	0.6	-0.4	0.4
Mean	4,366	4,723	4,573	Median	0.6	0.3	0.3
Std.Dev.	2,455	2,677	2,438	Std.Dev.	0.3	1.8	0.4
WEST							
Sichuan	8,161	8,138	8,050		0.0	-0.4	-0.1
Xinjiang	1,661	2,131	2,209		1.9	1.2	1.8
Qinghai	481	554	568		1.1	0.8	1.0
Gansu	2,438	2,628	2,564		0.6	-0.8	0.3
Chongqing	3,002	2,839	2,919		-0.4	0.9	-0.2
Shaanxi	3,513	3,762	3,743		0.5	-0.2	0.4
Yunnan	3,990	4,543	4,631		1.0	0.6	0.9
Guizhou	3,508	3,793	3,469		0.6	-2.9	-0.1
Total	26,754	28,388	28,152	Mean	0.7	-0.1	0.5
Mean	3,344	3,549	3,519	Median	0.6	0.2	0.4
Std.Dev.	2,256	2,220	2,188	Std.Dev.	0.7	1.4	0.7
ALL PROVINCES							
Total	119,664	131,154	133,098	Mean	0.8	1.4	0.9
Mean	4,126	4,523	4,590	Median	0.6	0.8	0.6
Std.Dev	2,454	2,699	2,661	Std.Dev.	0.6	4.4	1.0

TABLE 2. Energy consumption per capita and growth rate: 1995-2011

Province	Consumption per capita (C/N)									C/N Growth Rate (%)								
	Coal[a]			Electricity[b]			Liq. Pet. Gas[a]			Coal			Electricity			Liq. Pet. Gas		
	1995	2008	2011	1995	2008	2011	1995	2008	2011	95-08	08-11	95-11	95-08	08-11	95-11	95-08	08-11	95-11
EAST																		
Shanghai	1.558	0.390	0.185	2.327	10.535	7.464	0.128	0.233	0.146	-10.1	-22.1	-12.5	12.3	-10.9	7.6	4.7	-14.5	0.8
Beijing	3.222	1.509	1.385	1.447	6.861	7.170	0.114	0.130	0.105	-5.7	-2.8	-5.1	12.7	1.5	10.5	1.0	-6.8	-0.5
Tianjin	0.888	0.270	0.289	0.864	2.511	3.005	0.024	0.031	0.033	-8.8	2.4	-6.8	8.6	6.2	8.1	2.0	2.3	2.0
Liaoning	1.744	0.974	0.928	1.500	3.810	4.280	0.117	0.120	0.199	-4.4	-1.6	-3.9	7.4	4.0	6.8	0.2	18.6	3.4
Jiangsu	0.549	0.105	0.027	1.085	3.853	5.168	0.051	0.116	0.098	-11.9	-36.8	-17.2	10.2	10.3	10.2	6.5	-5.4	4.2
Zhejiang	0.351	0.150	0.112	1.315	5.018	6.455	0.104	0.365	0.417	-6.3	-9.4	-6.9	10.9	8.8	10.5	10.1	4.6	9.0
Guangdong	0.368	0.078	0.065	1.519	4.820	5.929	0.225	0.433	0.461	-11.3	-6.1	-10.3	9.3	7.2	8.9	5.2	2.1	4.6
Shandong	0.388	0.419	0.514	0.914	3.126	4.028	0.015	0.132	0.148	0.6	7.0	1.8	9.9	8.8	9.7	18.2	4.0	15.4
Fujian	0.560	0.363	0.253	1.071	5.238	7.270	0.044	0.178	0.113	-3.3	-11.3	-4.8	13.0	11.5	12.7	11.4	-14.0	6.1
Guangxi	0.061	0.046	0.070	0.687	2.265	3.657	0.034	0.155	0.182	-2.1	14.6	0.9	9.6	17.3	11.0	12.3	5.5	11.0
Hebei	2.354	1.837	1.871	0.789	3.131	4.370	0.024	0.053	0.110	-1.9	0.6	-1.4	11.2	11.8	11.3	6.5	27.2	10.1
Mean	1.095	0.558	0.518	1.229	4.652	5.345	0.080	0.177	0.183	-5.9	-6.0	-6.0	10.5	6.9	9.8	7.1	2.1	6.0
Median	0.560	0.363	0.253	1.085	3.853	5.168	0.051	0.132	0.146	-5.7	-2.8	-5.1	10.2	8.8	10.2	6.5	2.3	4.6
Std. Deviation	1.001	0.612	0.616	0.467	2.372	1.590	0.064	0.123	0.134	4.2	14.1	5.7	1.8	7.3	1.8	5.5	12.6	4.9
CENTRAL																		
Heilongjiang	1.502	0.276	1.040	1.100	3.285	3.799	0.110	0.228	0.264	-12.2	55.6	-2.3	8.8	5.0	8.1	5.7	5.0	5.6
Jilin	1.248	0.557	0.711	1.334	2.914	4.003	0.055	0.054	0.158	-6.0	8.5	-3.5	6.2	11.2	7.1	-0.2	43.2	6.8
Hubei	1.023	0.955	0.889	0.645	2.628	3.665	0.017	0.103	0.104	-0.5	-2.3	-0.9	11.4	11.7	11.5	14.8	0.3	11.9
Shanxi	2.002	2.943	3.322	0.657	2.338	3.337	0.005	0.054	0.053	3.0	4.1	3.2	10.3	12.6	10.7	20.0	-0.8	15.8
Hunan	1.247	0.796	0.925	0.525	2.446	3.481	0.013	0.046	0.050	-3.4	5.1	-1.8	12.6	12.5	12.5	10.6	2.2	9.0
Hainan	.	.	.	0.296	1.947	3.105	0.036	0.085	0.124	.	.	.	15.6	16.8	15.8	6.9	13.5	8.1
Anhui	0.542	0.489	0.379	0.547	1.997	3.210	0.015	0.048	0.070	-0.8	-8.2	-2.2	10.5	17.1	11.7	9.4	13.0	10.1
Jianxi	0.744	0.434	0.314	0.357	2.041	2.784	0.016	0.074	0.089	-4.1	-10.2	-5.2	14.4	10.9	13.7	12.5	6.2	11.3
Henan	1.226	1.076	1.059	0.461	2.004	3.660	0.009	0.021	0.054	-1.0	-0.5	-0.9	12.0	22.2	13.8	6.8	36.1	11.8
Inner Mongolia	0.630	3.368	6.817	0.683	2.463	3.989	0.006	0.020	0.050	13.8	26.5	16.0	10.4	17.4	11.7	9.0	36.6	13.7
Mean	1.129	1.210	1.717	0.661	2.406	3.503	0.028	0.073	0.102	-1.2	8.7	0.3	11.2	13.7	11.7	9.6	15.5	10.4
Median	1.226	0.796	0.925	0.596	2.392	3.571	0.016	0.054	0.080	-1.0	4.1	-1.8	10.9	12.5	11.7	9.2	9.6	10.7
Std. Deviation	0.460	1.137	2.108	0.324	0.443	0.396	0.033	0.060	0.068	6.3	18.5	5.7	2.7	4.8	2.6	5.5	16.7	3.1

[a] Mtce per million habitants

[b] TWh per million habitants

Table 2. Continued:

Province	Consumption per capita (C/N)									C/N Growth Rate								
	Coal			Electricity			Liq. Pet. Gas			Coal			Electricity			Liq. Pet. Gas		
	1995	2008	2011	1995	2008	2011	1995	2008	2011	95-08	08-11	95-11	95-08	08-11	95-11	95-08	08-11	95-11
WEST																		
Sichuan	1.934	0.927	0.668	1.017	2.341	3.416	.	.	.	-5.5	-10.3	-6.4	6.6	13.4	7.9	.	.	.
Xinjiang	4.171	1.090	1.159	0.609	1.809	2.497	0.052	0.054	0.052	-9.8	2.1	-7.7	8.7	11.3	9.2	0.4	-1.7	0.0
Qinghai	2.400	1.938	2.257	0.532	2.165	2.795	0.081	0.040	0.041	-1.6	5.2	-0.4	11.4	8.9	10.9	-5.3	1.1	-4.2
Gansu	1.903	1.648	1.981	0.566	1.546	2.435	0.010	0.021	0.022	-1.1	6.3	0.3	8.0	16.4	9.6	5.9	1.6	5.1
Chongqing	0.673	0.607	0.673	0.646	2.994	4.086	.	.	.	-0.8	3.5	0.0	12.5	10.9	12.2	.	.	.
Shaanxi	1.385	0.284	1.169	0.561	2.005	3.473	0.033	0.186	0.059	-11.5	60.3	-1.1	10.3	20.1	12.1	14.3	-31.9	3.8
Yunnan	1.213	0.644	0.767	0.462	2.346	2.867	.	.	.	-4.8	6.0	-2.8	13.3	6.9	12.1	.	.	. .
Guizhou	2.936	1.720	2.059	0.385	2.341	4.182	0.043	0.027	0.028	-4.0	6.2	-2.2	14.9	21.3	16.1	-3.7	1.1	-2.8
Mean	2.077	1.107	1.342	0.597	2.193	3.219	0.027	0.041	0.025	-4.9	9.9	-2.5	10.7	13.7	11.3	2.3	-6.0	0.4
Median	1.919	1.008	1.164	0.563	2.253	3.142	0.021	0.024	0.025	-4.4	5.6	-1.6	10.8	12.4	11.5	0.4	1.1	0.0
Std. Deviation	1.100	0.602	0.661	0.189	0.433	0.678	0.030	0.062	0.024	4.0	21.1	3.0	2.8	5.2	2.5	8.0	14.6	4.0
ALL PROVINCES																		
Mean	1.387	0.925	1.139	0.859	3.199	4.124	0.048	0.104	0.111	-3.1	7.2	-1.2	10.6	8.8	10.3	6.2	2.4	5.4
Median	1.236	0.625	0.828	0.683	2.463	3.665	0.033	0.054	0.089	-5.1	2.2	-1.5	10.4	3.1	-30.5	4.0	3.9	6.5
Std. Deviation	0.973	0.841	1.361	0.456	1.861	1.423	0.052	0.105	0.111	-1.1	3.8	-8.1	11.4	-2.0	-22.5	5.6	0.4	4.8

Table 3. Cluster analysis

	Rural vs urban household energy consumption	b-coef	t-stat
First club	Electricity consumption-rural, electricity consumption-urban	-1.100	-1.600
Second club	Coal consumption-rural, coal consumption-urban	1.615	2.643
	Coal consumption	**b-coef**	**t-stat**
First club	Beijing, Hebei, Inner Mongolia, Shanxi, Gansu, Qinghai, Guangxi, and Guizhou	-0.253	-1.948
Second club	Shandong, Heilongjiang, Jilin, Liaoning, Shaanxi, Xinjiang, Henan, Hubei, Hunan, Sichuan, Yunnan, and Chongqing	0.666	1.096
Third club	Anhui, Fujian, Jiangxi, Shanghai, Zhejiang, and Tianjin	-0.769	-0.843
Fourth club	Jiangsu and Guangdong	-1.195	-0.487
	Electricity consumption	**b-coef**	**t-stat**
First club	Anhui, Fujian, Jiangsu, Jiangxi, Shanghai, Zhejiang, Beijing, Hebei, Inner Mongolia, Shanxi, Qinghai, Shaanxi, Guangdong, Guangxi, Hainan, Henan, Hubei, Hunan, Guizhou, and Yunnan	0.794	1.715
Second club	Shandong, Tianjin, Heilongjiang, Jilin, Liaoning, Gansu, Xinjiang, Sichuan, and Chongqing	0.335	0.793
	Liquid gas consumption	**b-coef**	**t-stat**
First club	Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Shanghai, Zhejiang, Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin, Heilongjiang, Jilin, Liaoning, Gansu, Guangdong, Guangxi, Hainan, Henan, Hubei, Hunan, and Guizhou	-9.180	-3.295
Second club	Qinghai, Shaanxi, and Xinjiang	8.806	4.180

Figure 1. Evolution of residential energy consumption per capita by provinces

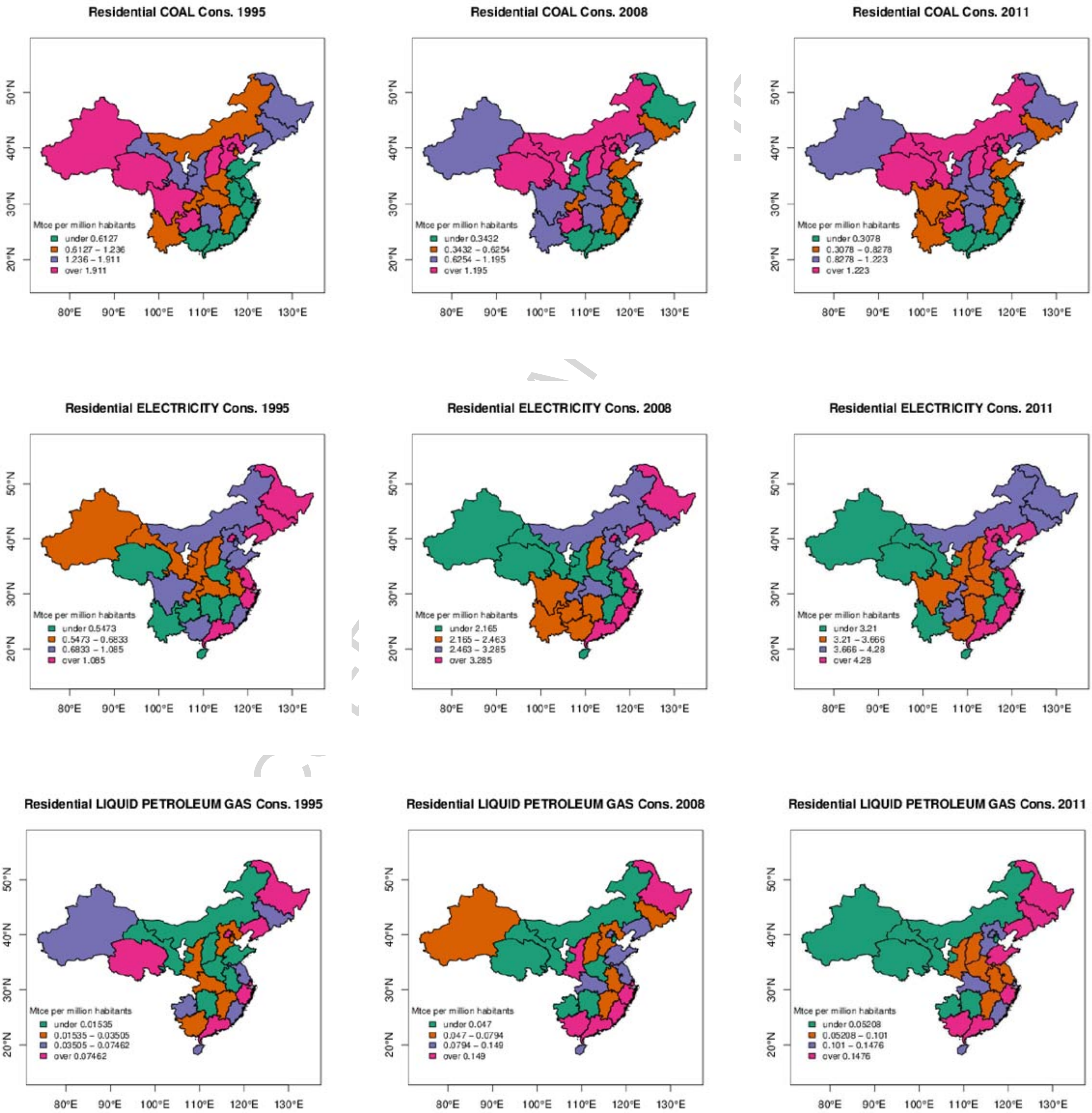


FIGURE 2. Coal and electricity per capita consumption by urban share (1995-2011)

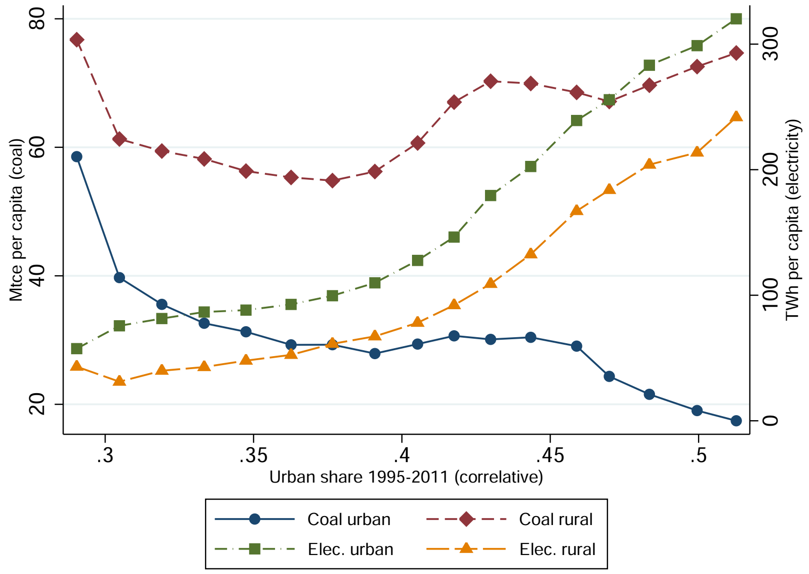
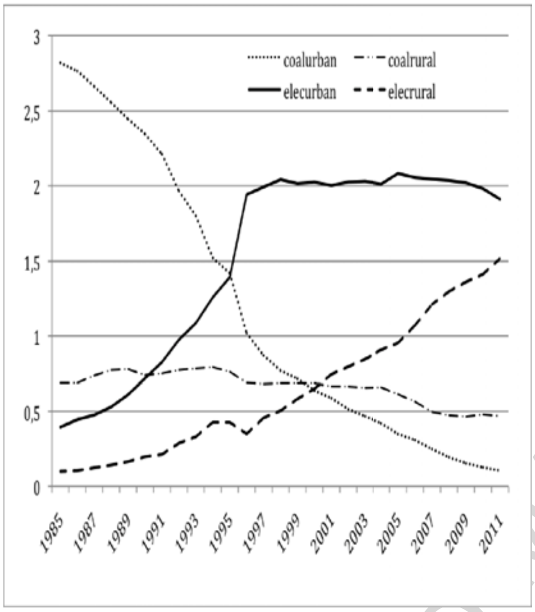
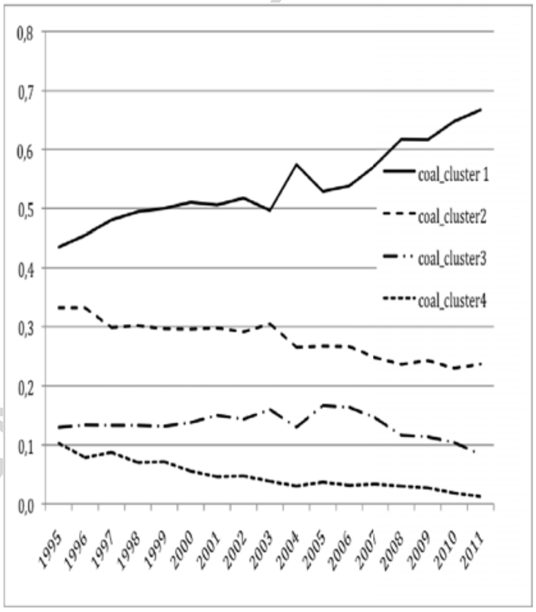


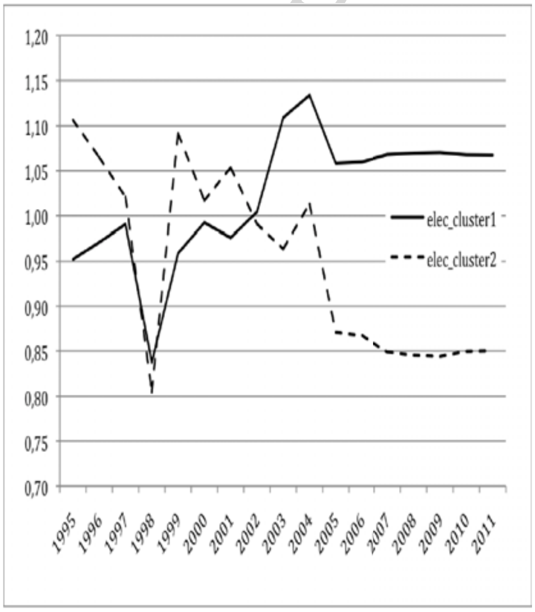
Figure 3. Transition path for the estimated clusters



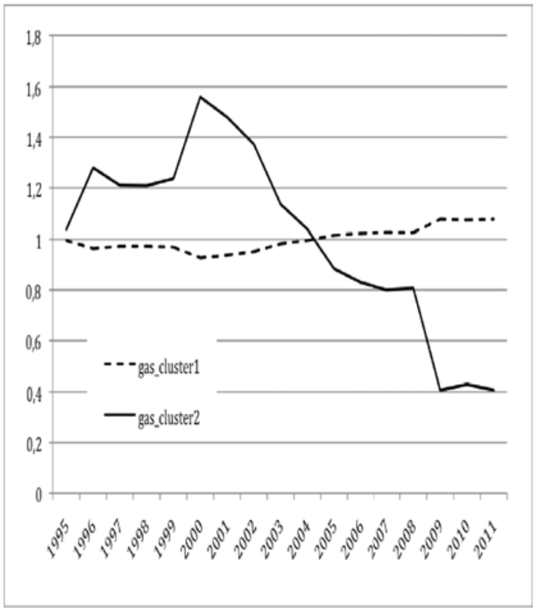
(a) Urban versus rural energy consumption



(b) Coal consumption

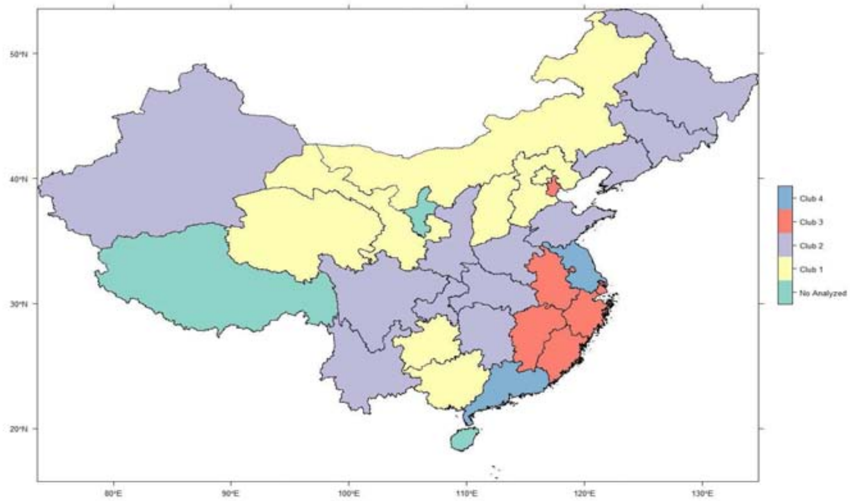


(c) Electricity consumption

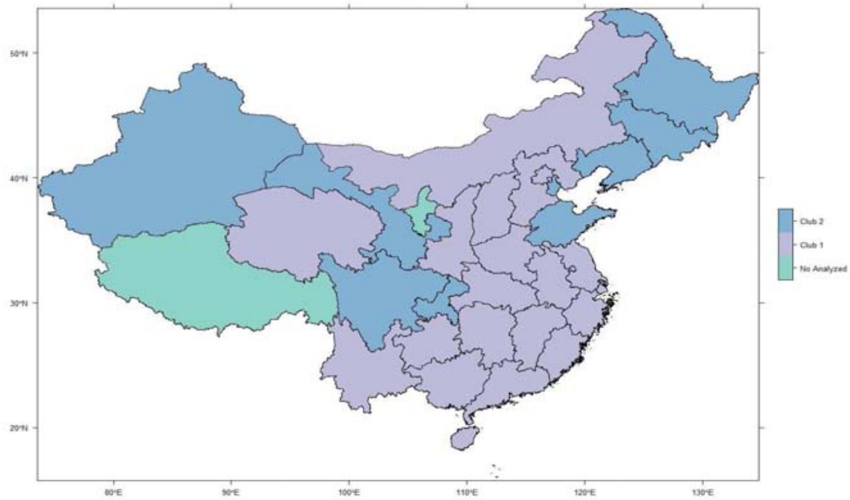


(d) Liquid gas consumption

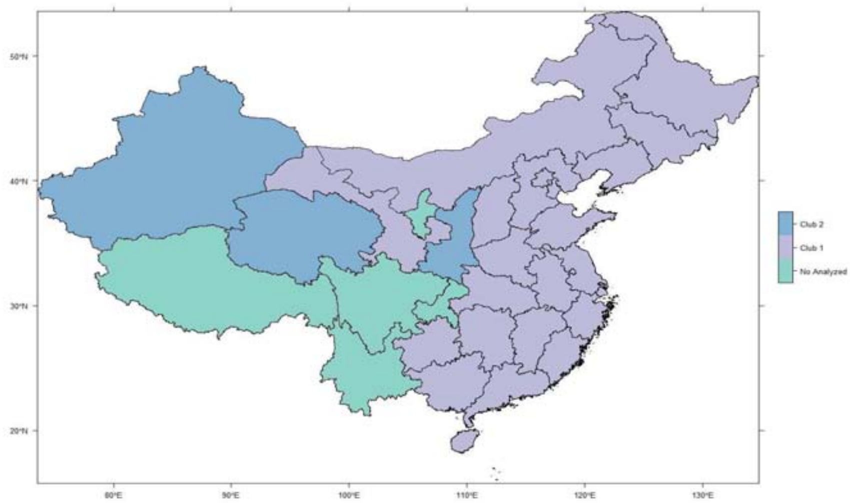
Figure 4. Club convergence across Chinese regions



(a) Coal consumption



(b) Electricity consumption



(c) Liquid gas consumption