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# DIVERGENCE AND CLUBS CONVERGENCE OF THE GLOBAL ENERGY

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**ABSTRACT**

The aim of this paper is to investigate the convergence behaviour of the share of global energy mix measured by primary energy consumption. The standard literature employ panel data stationary tests, which suggest that the hypothesis of convergence is supported by the data. However, some drawbacks exist. These studies rely on methods that do not necessarily imply a sufficient condition for convergence. In this paper, the concept of relative convergence proposed by Philips and Sul (2007) is adopted, which employs a time varying idiosyncratic component. We choose to work on the global primary energy consumption of various sources and investigate its long run dynamic behaviour by source. The key finding of this paper is that, when allowing for the case of clubs of convergence, we identify two distinct clubs: renewable energy and non-renewable energy clubs. Our findings also suggest that non-renewable primary energy consumption at the global level remains dominant.

**Keywords:** Energy mix, renewable and non-renewable energy, convergence, clubs of convergence.

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## 1. Introduction

The dramatic peaks in energy prices may have led consumers to demand a different energy source (Allen 2009). Also, major increases in energy consumption could trigger a transition from one energy source to another. Countries that remain dependent on oil become vulnerable to oil price spikes and supply disruptions. For example, until the 1973 oil price shock, few people in the United States questioned the extent to which their lifestyles depended on oil. The oil crisis of 1973 changed their view. As a result, policy makers have aimed to manage risk by diversifying suppliers or enhancing substitution among different oil types. This may have led to an increased diversification of energy from other sources such as natural gas and coal. For example, nuclear power and natural gas substituted for crude oil in electricity generation, and crude oil was diverted to transport services (Ruhl et. al. 2012).

This diversification and gradual specialisation of energy is a result of the comparative efficiency of each of the commercial fuels, in terms of production and conversion to usable energy, and of its contribution to GDP growth (Ruhl et. al. 2012). After World War II, oil was the major provider of energy until supplies were disrupted in the 1970s (Hartshorn 1993) leading to the drive for diversification with other fuels such as natural gas and nuclear energy entering the scene. In recent years, there has been a drive towards harnessing energy from renewable sources such as wind or solar sources. This has led to an energy mix, comprising of oil, natural gas, nuclear, wind and solar among others. This process of a change in the energy mix would be a result of the fact that fuels can now be traded across nearly all international borders, technologies are becoming increasingly shared internationally, and consumption baskets (determining the end-use of energy) are becoming standardised across formerly very different countries (Ruhl et. al. 2012). Today there is great focus on the next transition – on the expectation or the possibility of a substantial change in the energy mix. What would be the nature of the changing mix? The answer to this question will have a profound impact on the global energy system, on producers and consumers alike and on markets everywhere.

A significant volume of studies deal with the convergence of energy consumption in its various forms including renewable and non-renewable energy sources. The literature employs various measures of energy consumption including total energy consumption and energy prices. Both strands apply the concept of stochastic convergence, which is tested using unit root and/ or stationarity of time series tests on the relative time series (e.g. data expressed as ratios of the cross-sectional sample mean of all series in the sample) to assess the presence of the convergence hypothesis. This paper adds to this strand of the literature by employing an alternative approach, that is convergence clubs, which allows us to focus on the dynamic patterns of primary energy consumption.

To elaborate, recent studies have mostly focused on the total energy consumption, final energy consumption or a particular source of energy consumption across economies (countries or states within a country). This does not offer an analysis concerning the dynamic behaviour of various types of primary energy consumption (including both renewable and non-renewable sources), which has not been consistently the same across various sources of energy. In this context, Matias and Devezas (2007) argue that primary energy consumption in the last two centuries has not been the same for all renewable and non-renewable energy sources. According to Matias and Devezas (2007) fossil fuel energy sources are dominant and their levels of consumptions are significantly higher than those of renewable sources. This might be due to economic fluctuations and the decline of domestic energy sources. For example, due to business cycles, the European Union is more likely to rely more on energy imports, in particular crude oil and natural gas. According to the EU commission report (COM(2014)) EU energy markets had to consider the long-term prospects of the industry in terms of replacing the decreasing domestic production with imports from EU trading partners. This implies that growth targets might affect the type of energy sources economies might choose to switch to or the bundle of energy mix consistent with the economic needs. This gives rise to a substitution behaviour where each sector of energy dominates the market at the expense of the other due to the rise and fall of the market shares of each sector of energy (Bodger et al, 1989). Therefore, we attempt in this paper to apply the concept of convergence to investigate the nature of the time path in primary energy consumption. This also include identifying the energy mix, a task that requires an appropriate econometric methodology. We argue that the approaches based on the concept of stochastic convergence may not be suitable for such a task.

Stochastic convergence suggests studying the dynamic behaviour of a time series in the long run. If the dynamics of a time series is stable in the long run then the time series is said to be convergent to the long run level. In other words, the shocks to the series do not have an everlasting effect and dissipate to the long run level over time. The main implications of this concept is that the stationarity of data of all different series or economies considered is taken as a sign of an overall convergence. This refers to the case when all different series are convergent to a common stochastic trend or steady state. This, however, is not necessarily true. The presence of stationarity in the trend of an individual series does not necessarily confirm the presence of a common trend for all the series in the data, even when these series are expressed as relative to the cross-sectional average of all series being tested. In other words, the presence of stochastic convergence does not guarantee the presence of a unique time path (or long-run level) to which all the series being tested converge, nor rules out the possibility of the presence of clubs of convergence, the case when multiple time paths or long run levels exist to which subsets of series converge.

The concept of clubs of convergence has been dominantly discussed in the context of income convergence and CO2 emissions. In the case of income, early contributions include Chatterji (1992) where 'clubs', consists of a club for convergence and a club for divergence. However the approach by Chatterji (1992) is conceptual[2], as it assumes implicitly that members of the convergent club to be homogeneous in the sense that they all converge to the same steady state or long run level. In the same spirit, stochastic convergence can also be interpreted when we have a mixture of stationary and nonstationary, where stochastically convergent series form a convergence group and non-convergent series form a divergent group. This conceptualisation of clubs of convergence is also restricted by the assumption about the nature of the long run. In another contribution by Quah (1997), reference is made to two clubs: a club of rich economies and that of poor economies. Testing for the presence of these clubs under Quah (1997) relies on informal inspection of the distribution of the data, which may lead to erroneous identification of the clubs. Moreover, restricting the number of clubs to two rules the presence of other clubs, which would otherwise be identified. Thus, a more general framework to test for 'overall' convergence and clubs of convergence that allows for both the possibility of the existence of divergence groups as well as convergence clubs with multiple long run levels would be appropriate. In the case of CO2 emissions, there have been studies that determine whether emissions converge to a long run level which are consistent with environmental agreements and targets (see Aldy 2006, Barassi et. al. 2008, 2011), Westerlund and Basher (2008)). While there is no explicit reference made to clubs of convergence, one can make an implicit inference that there can be two clubs, based on the empirical literature on stochastic

[2] This is indeed true if we take into account the context within which the concept of Chaterji (1992) clubs of convergence developed. Namely, the approach is consistent with the literature of income convergence where that assumes the presence of one long run level to which all economies would converge to.

convergence; a club of convergence (i.e. when the unit root hypothesis is rejected) and another of divergence (i.e. when the unit root hypothesis is not rejected).

The issue of convergence in energy consumption has been dealt with leading to a large volume of literature. The findings in recent studies are generally mixed. While early studies consistently reject the convergence hypothesis, recent studies tend to differ and on balance, tend to concur convergence of energy consumption. For example, Payne et al (2017) find evidence in support of stochastic convergence but the evidence is solely based on fossil fuels data. This may suggest the presence of a common trend that drives the dynamics of energy consumption of the same nature (e.g. non-renewable). This, however, is in contrast with the conclusions reached by Mohammadi and Ram (2017), which indicate the presence of divergence in the US energy consumption across the states. Meng et al (2013) argue that the rejection of convergence hypothesis is due to erroneous conclusions unit root test report due to the presence of structural breaks (see Perron 1989). Once the breaks are accounted for in a panel data framework, Meng et al (2013) show that energy use in OECD countries are stationary and are in favour of convergence. The study however, is on per capita energy use, which includes final energy consumption and does not distinguish between the sources of energy (i.e. renewable and non-renewable) with no information about the dynamic behaviour of primary energy consumption and the energy mix. The studies that report convergence of energy consumption, either implicitly assume the hypothesis of convergence to hold (see Jakob et. al. (2012)) or employ panel data stationarity tests, LM type tests, and find evidence of convergence. For instance, the evidence in Hao et al (2015), Mishra and Smyth (2014), Lee and Lee (2009), amongst others, find that energy consumption follows a stationary process and therefore conclude the convergence hypothesis to hold. Similar to Meng et al (2013), these studies employ (i) data that do not necessarily reflect primary energy consumption by sources and (ii) the concept of stochastic convergence to be biased in favour of the convergence hypothesis. These two common features of the existing literature may pose a limitation and give a rise to a research gap that we aim to address.

In this paper, using a method of 'convergence clubs' due to Phillips and Sul (2007), PS hereafter, we aim to investigate whether energy consumption from different sources has converged to single source and hence can be considered as a 'standardized'; or are there different groups that can be classified as renewables and non-renewables, leading to different 'clubs'.

PS introduce a framework that allows for various possibilities concerning the convergence hypotheses. In the context of this framework, the hypothesis of the overall convergence is tested first. The hypotheses assess whether all series in the data converge to a common long run trend. This hypothesis is of great relevance and offer an alternative to stochastic convergence since the latter do not formally test for the presence of common long run time path to which all the series in the data converge. Second, if the overall convergence is rejected, unlike existing tests the framework allows for the cases of clubs of convergence and clubs of divergence. The number of clubs identified using this approach is limited only by data availability. The PS approach proposes an idiosyncratic element that is allowed to evolve over time and capture heterogeneity across individual using a time varying factor-loading coefficient. The test implemented in this approach does not rely on any particular assumption concerning trend stationarity or stochastic non-stationarity of the variable of interest and the common factors across individuals in the panel, which makes it an attractive approach and obviates the issues of high persistence and unit roots when dealing with convergence in a dynamic panel framework.

The aim of this paper is, therefore, to study the convergence of primary energy consumption using a broader and more general framework proposed by PS. This framework which allows for the possibilities of (i) overall convergence and (ii) clubs of convergence and/ or divergence, and (iii) no convergence. Using the method of PS, we find evidence that two clubs have emerged over time since the 1960s. One club comprises of fossil fuels (non-renewable) and the other club which includes non-fossil fuels (renewables). These two clubs are distinct showing no signs of convergence which implies that there is still no sign that the world will not be dominated by fossil fuels in the immediate future, however, the emergence of a club comprising of non-fossil fuels may suggest possible convergence in the future.

The remaining paper is organized as follows. Section 2 gives some background about the energy mix and transitions. This is followed by the econometric methodology which describes the novel approach due to PS in section 3. Section 4 describes the data and the empirical results. Finally, section 5 concludes.

## 2. Background

There is wide variation in the economic performance of different countries and regions around the world. In recent years among the OECD countries, the pace of economic growth has been variable but currently is slow in comparison with the emerging economies of the non-OECD countries such as China and India. For example, in the United States and Europe, the debt situation remains grim and is one of the main reasons of uncertainty for future economic growth. Japan, whose economy had been sluggish before the devastating earthquake in March 2011, is recovering from its third recession in 3 years.

China has been among the world's fastest growing economies for the past two decades. From 1990 to 2010, China's economy grew by an average of 9.95 percent per year and India’s economy has grown by about 6.5 percent per year. Although the two countries' economic growth remained strong through the global recession, both slowed in 2013 to rates much lower than analysts had predicted at the start of the year. Since 2011 China's economy grew by an average of 8.2 percent per year and India’s economy by about 5.46 percent per year. In 2013 alone, GDP in China increased by 6.7 percent, its lowest annual growth rate since 2000, while India’s GDP growth slowed to 5.01 percent in 2013[3].

In spite of the recent slowdown, China and India lead in energy demand growth. Since 1990, energy consumption in both countries as a share of total world energy use has increased significantly; together, they accounted for about 10 percent of total world energy consumption in 1990 and nearly 24 percent in 2010 (IEO 2013). Ruhl (2010) notes that economic growth in emerging market economies has caused unprecedented structural transformation with a large migration from low energy intensive agricultural sector to energy intensive sectors such as construction and industry. China and India are cases in point. Besides to power the growth in these countries, coal has been a popular choice in non-OECD countries given that it is cheaper and widely available compared to oil and natural gas. According to 2008 figures, China alone accounts for 43% of total coal consumption (Ruhl 2010). Since 2000, the world consumption of coal has increased at a faster rate than any of the other primary energy types (IEO 2013). In spite of the sharp increase in global coal consumption, the share of oil has been buoyant as well given the demand for increased transportation needs from the emerging economies such as China and India. Both countries have huge populations, increased scale of urbanisation from the increased incomes, which has caused the need for increased mobility and transportation

[3] Data taken from the World Development Indicators.

needs from a change in lifestyle (Ruhl 2010). Also, natural gas remains an important source of energy in the EU where it is relatively cheaper than coal to produce electricity.

The three fossil fuels crude oil, coal and natural gas fill about 80% of this global energy supply **(**BP Statistical Review 2013**)**. Fossil fuels are technically easy to exploit, and as of now still provide cheap energy, though concerns are being raised as to whether this dominant role may have to change in the future. The contribution of nuclear and hydropower which are only used to produce electricity to the global primary energy consumption is about 6% and 2%, respectively. The share of biomass on the global energy supply is about 10%. Out of this, about two-thirds is traditional biomass. Currently, there is no evidence that other renewable energy sources such as geothermal, solar, wind and tide energy currently play a significant role at a global level (0.7%) (BP Statistical Review 2013), but some countries actively support and make use of renewable energy. For example, in 2012 , 19% of electricity production in Denmark, 11% in Spain and Portugal, and 7% in Germany in  was derived from wind power (BP Statistical Review 2013).

There is a general view that fossil energy resources are limited, however, there has been intense debate as to whether these resources are gradually being depleted. The status of world energy is a contentious issue, polarised between advocates of peak oil who believe production will soon decline, and oil companies that say there is enough oil to last for decades. However, there is a growing belief, that the volume of oil that can be commercially exploited at prices the global economy has become accustomed to is limited and will soon decline. The result is that oil may soon shift from a demand-led market to a supply constrained market (Owen et al., 2010). For the moment, the demand for energy to meet our requirements is dependent upon the rapid and immediate diversification of the energy mix of various forms of energy. This would mean that with possible supply constraints, there will be a need for a transition to alternative energy sources where appropriate, and behavioural change and adaptation.

The demand for energy is rising across the globe, especially in emerging economies such as China and India which also have large populations. It needs to be seen what the future will show regarding the global energy mix. In the past, there have been alarming predictions by groups such as the Club of Rome that the production peak of oil world would be reached in the late 20th century. This was not exactly the case, and while corporate bodies claim that there is still enough fossil fuels, there are alternative studies such as a recent study by Aleklett et al. (2010), which concludes that the global oil production has very probably now passed its maximum. In any case, in the long run the world may very well struggle to provide affordable oil, and technological advancements such as horizontal drilling and hydraulic fracturing, as well as costly and less productive methods such as deep sea drilling may have to be used. As discussed by Schollnberger (2006), the global pattern of primary energy consumption will change profoundly during the 21st century, which will create a new energy mix.

## 3. Econometric Methodology

For the purpose of this paper, we employ the convergence test proposed by PS. The PS procedure provides a novel approach that relaxes the assumption about the stationarity of the time series and defines a concept of convergence and clubs of convergence along the lines of Phillips and Sul (2007).

The PS approach provides a procedure for identifying clubs of convergence endogenously in a very simple and convenient time series framework to test for convergence. It also includes the possibility of mobility and catching up. Moreover, this approach allows for clustering the time series depending on their individual transition path relative to common trend, which may lead to identifying steady states describing the level of income to which time series of the similar time path converge.

PS propose an idiosyncratic element that is allowed to evolve over time and capture heterogeneity across individual using a time varying factor-loading coefficient. The test implemented in this approach does not rely on any particular assumption concerning trend stationarity or stochastic non-stationarity of the variable of interest and the common factors across individuals in the panel, which makes it very attractive and solves the issue of unit roots and cointegration when dealing with convergence in time series panel framework.

Following the notation in PS, we can define the econometric model used to test for convergence and club of convergence as:

$$X_{it} = \delta_{it}\mu_t \tag{1}$$

Where $X_{it}$ is the dependent variable (i.e. the global share of primary energy consumption) observed across $i = 1,2, \dots, N$ individuals over the period $t = 1,2, \dots, T$. There are two terms in model (1), $\delta_{it}$ and $\mu_t$. The former term is an idiosyncratic element in the sense that it captures both time and individual specific effects. It measures the distance between $X_{it}$ and the common factor $\mu_t$., which represents the common stochastic trend in the panel. In other words, the coefficient $\delta_{it}$ measures of the share of the common factor $\mu_t$ each individual in the panel data experiences. In the context of this paper, we define a stochastic trend as the common factor term. Note that both elements are time varying.

The idiosyncratic element is defined as:

$$\delta_{it} = \delta_i + \sigma_i \zeta_{it} L(t)^{-1} t^{-\alpha} \quad (2)$$

where $\delta_i$ fixed, $\zeta_{it} \sim iid(0,1)$ across individuals $i = 1,2, \dots, N$ and dependent over time $t$; and, $L(t)$ is a slowly varying function of time, in which $L(t) \to \infty$ as $t \to \infty$.

Based on the formulation above, the null hypothesis of convergence is accepted if for all $\geq 0$ $\alpha \geq 0$, $\delta_{it} \to \delta_i$ or $H_0(\delta_i = \delta \; and \; \alpha \geq 0\,)$against the alternative of no convergence, that is, $H_A(\delta_i \neq \delta \; \forall \; i; \; and \; \alpha < 0\,)$.

Moreover, $X_{it}$ and $\mu_t$ do not need to be restricted to be trend stationary since expression (1) does not require either variable to be specified as stationary or non-stationary variable. The model is linearized to form a $logt$ regression, which can be used to directly test for the convergence and clubs of convergence hypotheses. The $logt$ regression can be expressed as:

$$log(H_1/H_t) - 2logL(t) = \hat{a} + \hat{b}logt + \hat{u}_t \quad (3)$$

where $t = \lfloor rT \rfloor, \lfloor rT \rfloor, \dots, T$, with $r > 0$, $L(t) = \log(t+1)$, $\hat{b} = 2\hat{\alpha}$ and $\hat{\alpha}$ is the estimate from (3). The term $H_1/H_t$ is the cross sectional variance ratio with the variance defined as:

$$H_t = \frac{1}{N} \sum_{i=1}^{N} (h_{it} - 1)^2 \quad (4)$$

and

$$h_{it} = X_{it} / \left[\frac{1}{N}\sum_{i=1}^{N} X_{it}\right] = \delta_{it} / \left[\frac{1}{N}\sum_{i=1}^{N} X\delta_{it}\right] \quad (5)$$

where $h_{it}$, in addition to displaying the relative transition path for individuals in our panel data, measures and captures the divergent behaviour of individuals from the common stochastic trend or the long-run growth path $\mu_t$.

The regression is run starting at $t = \lfloor rT \rfloor$, which is the integer part of $rT$ for some fraction $r > 0$. PS recommend to use $r = 0.3$. After running the regression, we cannot reject the null if the autocorrelation and heteroskedasticity robust one tail $t_{\hat{b}}$ statistic is above the critical value (e.g. at 5% level of significance, non-rejection of the null if $t_{\hat{b}} \geq 1.65$). Rejection of the null implies there is no *overall* convergence, but does not imply that there is no convergence at all. It may, in fact, imply that there may be relative convergence, which can be tested using a procedure by PS, which is alternatively a test for clusters of convergence.

Clustering individual series into subgroups requires finding evidence of the presence of clubs of convergence as the sample gets very large (i.e. $T \rightarrow \infty$). PS propose a simple procedure to identifying the clubs of convergence when the overall convergence hypothesis is statistically rejected[4]. In summary, the procedure includes defining a core subgroup $G_K$ that contains at least $K$ members (where $K = 2, \ldots, N$). This sub group is detected using an ordering procedure, which is based on the last observation of times series or the last $\lfloor rT \rfloor$ observations. Next, a size of $k$ subgroups can be constructed, namely $G_K = \{1,2, \ldots, k\}$ for $= \{2, \ldots, N\}$. This is followed by running the $logt$ regression test within each of these subgroups using data from $G_K$. The

[4] The reader is referred to Phillips and Sul (2007) for detailed discussion on the algorithm used to identify the clusters of convergence.

process chooses $k^*$ to maximize $t_k$ over all values for which $t_k > c$ for $k = \{2, \ldots, N\}$ and $c$ is the critical value.

## 4. Data and Empirical Results

Data are obtained from BP Statistical Review of World Energy (published June 2017)[5]. The data measures the primary energy consumption of non-renewable energy (coal, natural gas and oil) as well as alternative energy sources that include renewables (hydro, nuclear and others). The data is measured annually from 1965 to 2016 and the unit of measurement is in millions of tonnes oil equivalent (Mtoe).

Figure 1 illustrates the time dynamics of the primary consumption of the six energy sources under considerations. In general, all variables exhibit a positive trend over the sample, with a significant difference in terms of magnitudes with larger levels of the consumption of non-renewable sources of energy than that of renewable energy. The figure also shows the slow increase in the consumption of all energy sources with a slight increase in coal consumption and the tendency to decline of the consumption of nuclear energy. The gap in consumption has increased from around 1519 Mtoe recorded in 1965 to around 3826 Mtoe recorded in 2016, as shown in Figure 2. This gap, however, remains significantly wide.

**[Figures 1 and 2 about here]**

[5] Data can be obtained directly from: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html.

Figures 1 and 2, however, do not tell us much about the dynamics of the shares of consumption of each source of energy. Thus, we need to transform and express the data in terms of shares instead of levels. The shares are defined as

$$X_{it} = (Y_{it}/Total_t) \times 100 \tag{6}$$

where $Y_{it}$ is the $i$th variable of interest (i.e. oil, coal, gas, nuclear, hydro and other) over the period 1965-2017 and $Total$ is the total consumption observed over the same period. Figure 3 and Figure 4 illustrate the trends of global primary energy shares and the gap in global energy consumption shares respectively. Oil and coal shares show a tendency to decline, while gas shares seem to increase significantly in recent years as shown in Figure 3. The increases in renewable energy shares are significantly smaller. Although the gap is slightly declining between energy shares on the top and those on the bottom of the distribution, Figure 4 shows that the gap in global primary energy consumption shares remains significantly wider during the period 1965-2016.

**[Figures 3 and 4 about here]**

Then relative transition curves are approximated using equation (5) and illustrated in Figure 3. All relative transition curves displayed in Figure 5 are smoothed using the Hodrick-Prescott filter with smoothing parameter equal to 100[6]. The relative transition curves displayed in Figure 3 illustrate tendencies in global consumption of all six energy types. In general, global consumption of energy of all types fluctuates over time in a divergent pattern with a clear deviation away from the overall steady state represent by the horizontal line at value 1 (i.e.

[6] The value of 100 is chosen since the data are annual.

$h_{it} \rightarrow 1$ is not satisfied, see also Figure 5). We also notice that this line splits the shares of consumption series into two groups, a group with very high consumption shares including all traditional energy sources fluctuation over time above the steady state level and a group with low consumption shares including all renewable energy sources fluctuating below the steady state level. Moreover, as illustrated in Figure 5, oil is leading the global consumption, although there are signs of a decline in global consumption in recent years. In contrast to oil consumption, global consumption of coal has experienced a significant increase in recent years, while gas global consumption shows signs of steady increase before remaining stable during the last decade. Relative to the overall sample, renewable energy consumption is still very low with signs of increases over time. The above discussion leads us to test for convergence formally using the PS approach.

**[Figures 5 about here]**

**[Table 1 about here]**

The results of the PS procedure are reported in Table 1 using trimming rates $r$=0.3, 0.25 and 0.2. The additional trimming rates are confirmatory to the trimming rate of choice, $r$=0.3. The statistics reported in the overall test -44.76 is well below the 5% level of significance of the one tail critical value (*i.e.* -1.65), which implies that the overall convergence hypothesis is rejected. In other words, there is no convergence for all the energy shares series. However, applying the PS procedure, we can identify two distinct convergence clubs. The first club contains only fossil fuel based energy, while the second club contains non-fossil based renewable energy. The clubs are illustrated in Figure 6, which shows significant disparities across clubs over the sample span despite the slight increase in renewable energy shares (coinciding with a decrease in fossil fuels shares) noted in the mid-1980s. The dynamics of the two clubs remained relatively constant for the subsequent periods with higher steady of fossil fuels shares. The conclusions remains the same when using the trimming rates 0.25 and 0.20.

**[Figures 6 about here]**

## 5. Conclusions and Policy Implications

By eyeballing the data one may conclude that we have no clear conclusion about the global energy mix. One may conclude that in some dimensions, the impacts have been clear, while from another dimension, the historical data is less conclusive. The EIA has provided projections that world energy consumption will continue to grow and that the fastest growing energy source are renewable energy and nuclear power increasing at a rate of 2.5% per year. (Today in Energy, 2013). However, fossil fuels will continue to dominate the global energy use in the near future. Our analysis provides some clear characteristics of the data showing the formation of two clubs – fossil fuels on one hand and nuclear and renewables on the other. The first club will be the dominant club in the near future, and for the time being shows no sign of convergence with the second and more marginal club that comprises of renewables and nuclear energy.

The dominant club that comprises of fossil fuels comes as no surprise. According to IEA estimates oil demand is set to grow with half of global oil demand emanating from China. This is likely to continue as oil demand from the transportation sector is growing at a robust rate in China and India. More recently, coal (locally available and relatively cheap) has gained market share dramatically, driven by rapid economic and energy demand growth in China and other emerging economies. While coal has been the fastest growing energy source in recent years this growth has been unevenly distributed. The growth has been largely driven by China while the demand from OECD countries has been sluggish. Coal plays an important role in China and India and therefore coal demand is likely to grow in the future. Due to the size of the economy of China, different fuels within China's energy mix have emerged. The natural gas sector in China and the related challenges cannot be looked at in isolation from the global gas market. Gas consumption has increased four-fold since 2000 (OECD/IEA 2012).

The second club comprises nuclear, hydro and other renewables. Early on, rapid growth in nuclear output helped to displace oil in power generation (it also lost market share to natural gas in power generation, industrial applications, and space heating). More recently, the use of renewable fuels is increasing. Among these renewables are biofuels which displace oil in transportation directly; albeit in limited quantities. Energy security and diversification of the energy mix is a major policy driver for renewables. Growth of renewables generally contributes to energy diversification. Use of renewables can also reduce fuel imports and insulate the economy to some extent from the fossil fuel price rises and swings. This may increase energy security. However, concentrated growth of variable renewables can make it harder to balance power systems. The renewable energy sector is demonstrating its capacity to deliver cost reductions provided that appropriate policy frameworks are in place and enacted. However, economic barriers remain important in many cases Moreover, fossil fuels subsidies and the lack of global price on carbon are significant barriers to the competitiveness of renewables there is a general view that governments would be actively playing a role for the need of low carbon technologies which would have characteristics that make their choice preferable to fossil fuels. Over the years supply side technologies have influenced energy policy. A transition may be possible where the energy consumption behavior of individuals could be changed by demand side measures.

Nuclear capacity grew rapidly in the 1970s and 1980s as countries sought to reduce dependence on fossil fuels especially after the oil crisis of the 1970s. However, with the exception of Japan and Korea, growth stagnated in the 1990s. Reasons for this included the increased concerns about the safety following the incidents in the Three Mile Island 1979, and Chernobyl 1986. However, since 2000, there has been a renewed interest in nuclear energy, though in 2011 the Tsunami tragedy inflicted on the Fukushima Daiichi nuclear power plant. The impact on the growth of the nuclear generating capacity will become fully clear only in the coming years.

For the moment, fossil fuels still remains the world's leading source of energy. We have found evidence of an advance to a long term process of convergence of the shares of oil, coal, and natural gas in the global fuel mix. And this long term process of convergence, if it were to continue would indeed lead us to a world which would *not* be dominated by a single commercial fuel. While other sources of energy apart from fossil fuels, such as nuclear and renewable energy have shown signs of convergence of consumption shares, they are still distinct from the club formed by fossil fuels. However, in the distant future there is no reason to believe that the global mix of energy may change leading to different convergence clubs.

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**Table 1** Convergence and Clubs of Convergence Tests Results

| | 0.3 | 0.25 | 0.2 |
|---|---|---|---|
| Overall Test | $\hat{t} = -44.76$* <br> $\hat{\alpha} = -0.12$ | $\hat{t} = -67.13$* <br> $\hat{\alpha} = -0.12$ | $\hat{t} = -32.94$* <br> $\hat{\alpha} = -0.12$ |
| Club 1 | $\hat{t} = 21.92$ <br> $\hat{\alpha} = 0.51$ <br> [Oil, Gas, Coal] | $\hat{t} = 23.63$ <br> $\hat{\alpha} = 0.47$ <br> [Oil, Gas, Coal] | $\hat{t} = 20.81$ <br> $\hat{\alpha} = 0.41$ <br> [Oil, Gas, Coal] |
| Club 2 | $\hat{t} = 3.63$ <br> $\hat{\alpha} = 0.25$ <br> [Nuclear, Hydro, Others] | $\hat{t} = 3.49$ <br> $\hat{\alpha} = 0.23$ <br> [Nuclear, Hydro, Others] | $\hat{t} = 3.63$ <br> $\hat{\alpha} = 0.25$ <br> [Nuclear, Hydro, Others] |

Notes: (*) refers to the rejection of the null of convergence. $\hat{t}$ is the estimated one tail $t$ test statistic. The critical value at 5% level of significance is $t_c = -1.65$. The coefficient $\hat{\alpha}$ is the speed of convergence. The sample – in all series- covers the period 1965-2016 (T=52). The series are OIL, GAS, COAL, NUCLEAR, HYDRO and OTHERS. The trimming rate $r = 0.3$ is the recommended rate by Phillips and Sul (2007). The other trimming rates are reported for robustness check.

## Graphs

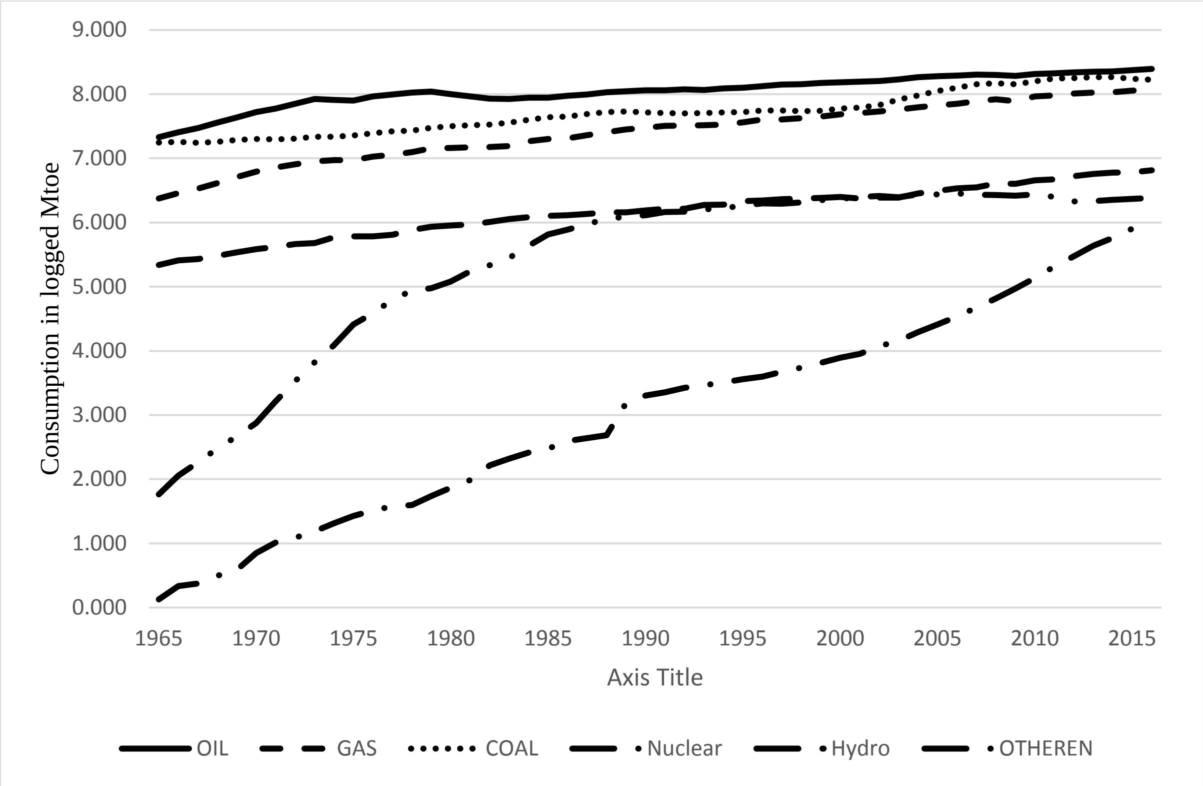


**Figure 1: Energy consumption over the period 1965-2016**

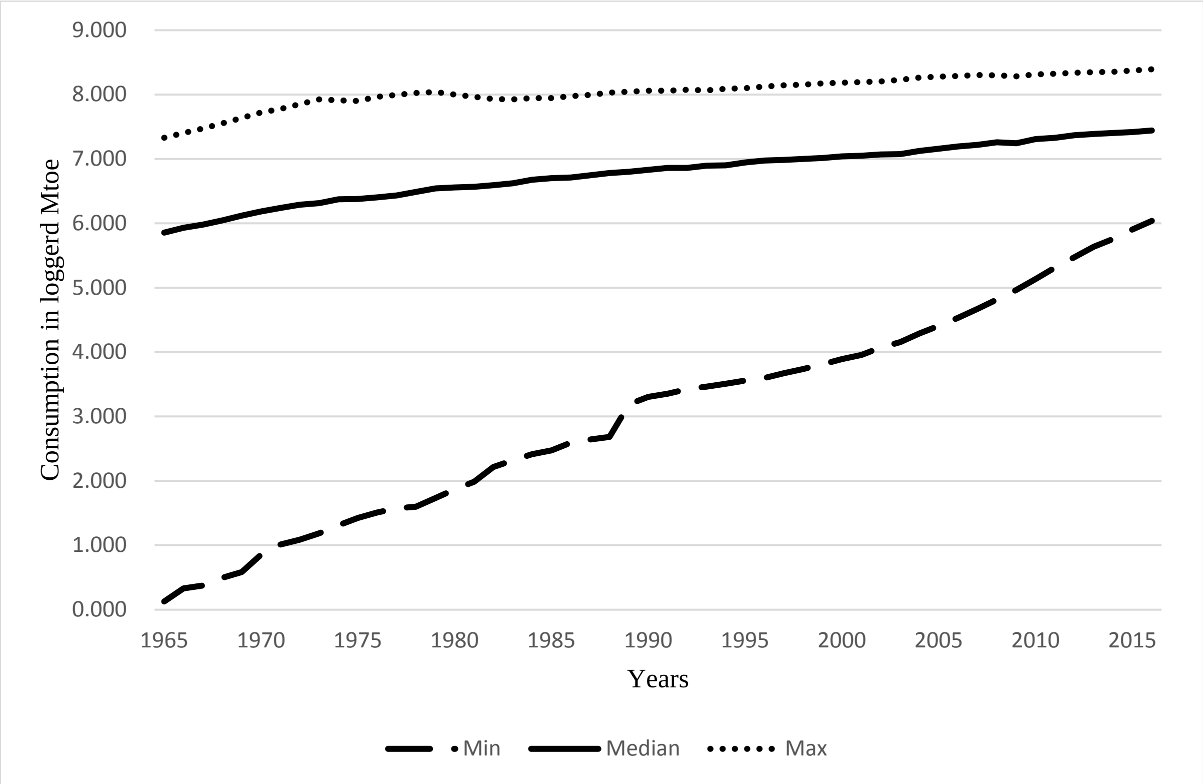


**Figure 2: Gap of consumption over the period 1965-2016**

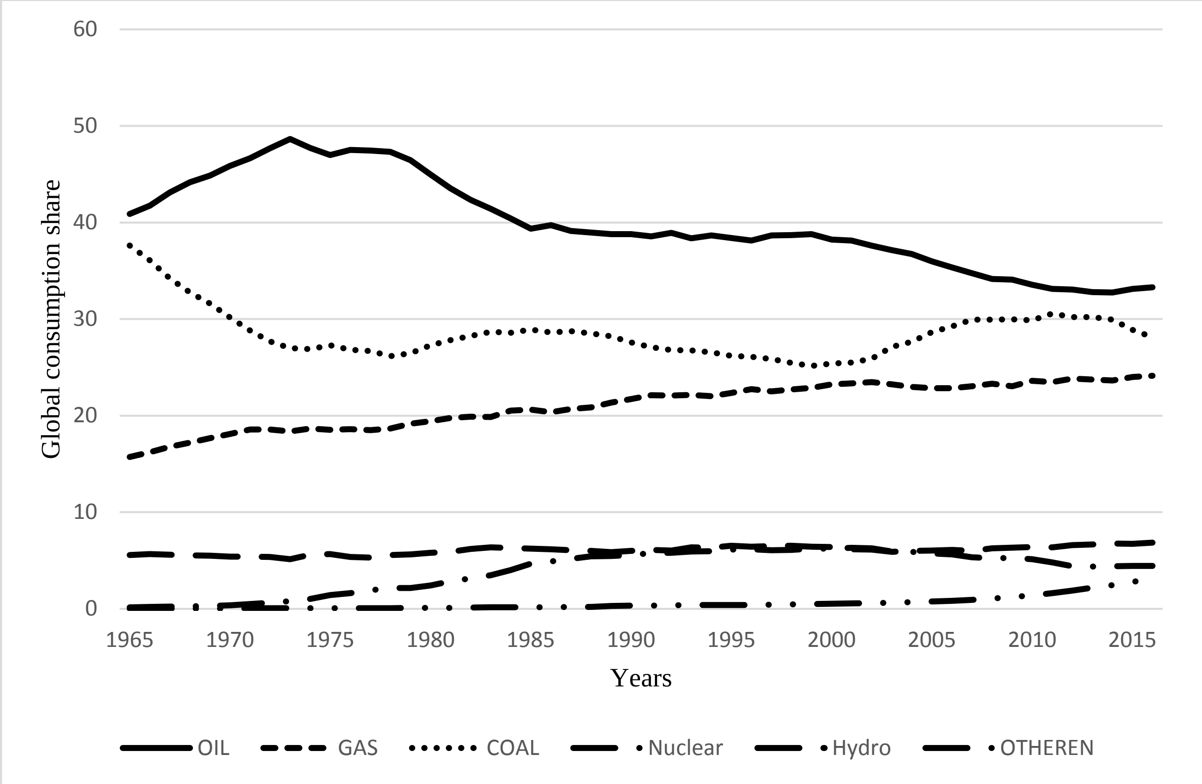


**Figure 3**: Global Energy Consumption Shares over the period 1965-2016

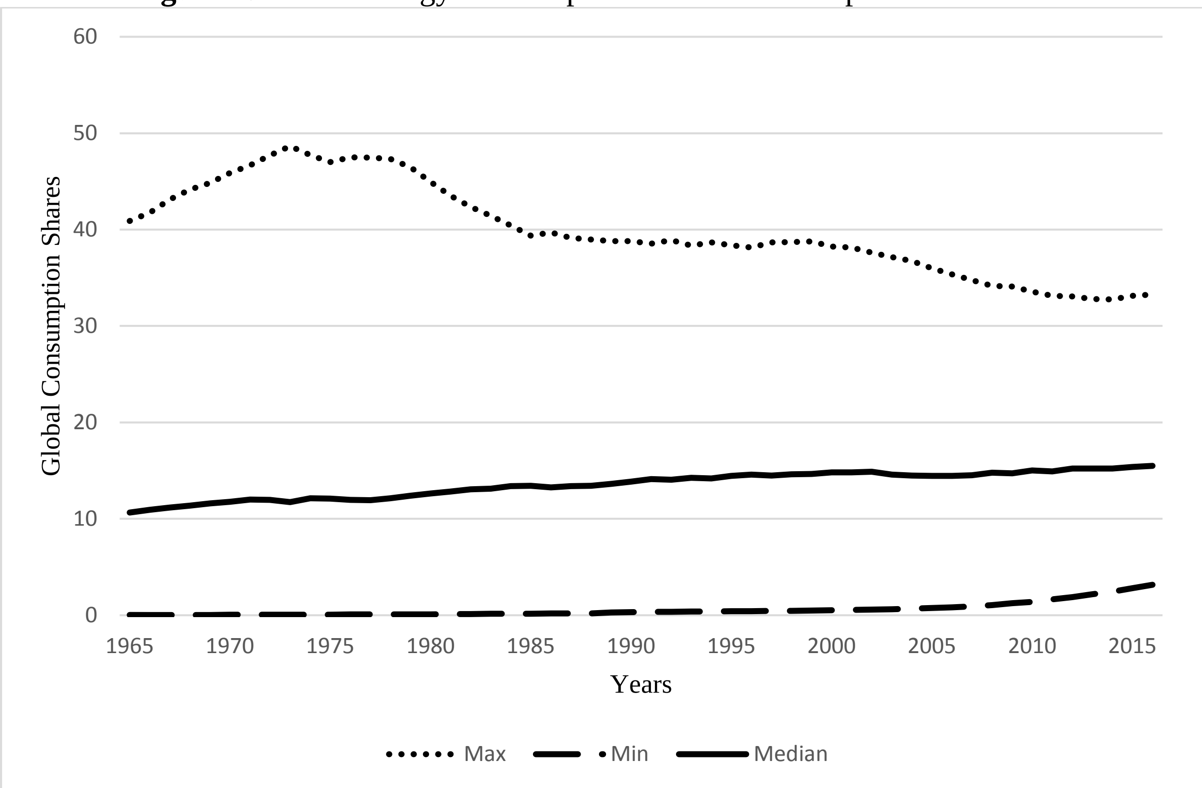


**Figure4**: Gap of global consumption share over the period 1965-2016

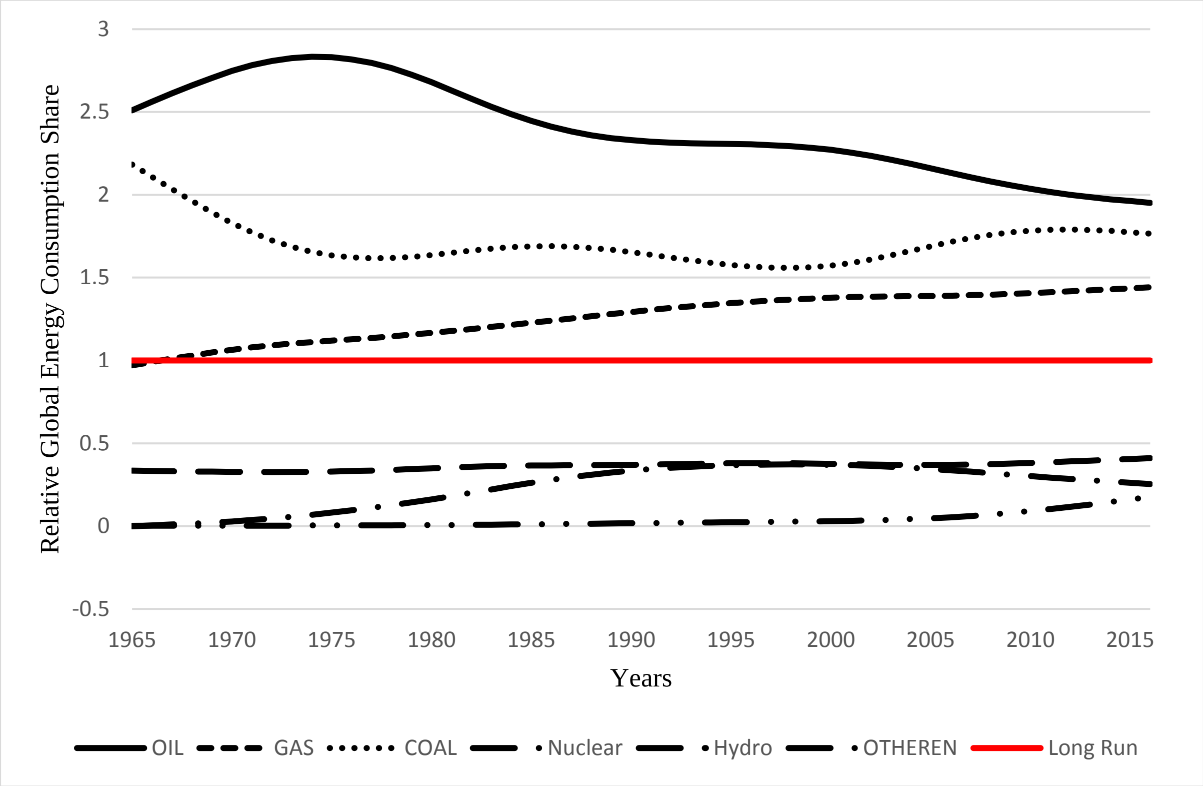

**Figure 5: Relative Transition Curves of Energy Shares**

**Figure 6: Relative Transition Curves- Estimated Clubs**