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Energy Consumption Transition and Human Development

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ENERGY CONSUMPTION TRANSITION AND HUMAN DEVELOPMENT

1. INTRODUCTION

Evidently, by century's end, energy-related carbon dioxide emissions would , at current rates, more than double, putting the world onto a potentially catastrophic trajectory which could lead to warming of 5 ℃ or more compared with preindustrial times. Human today is experiencing a dramatic shift to low-carbon development. The problems of the conventional energy order have led some to regard reinforcement of the status quo as folly and to instead champion sustainable energy strategies based on non-conventional sources and more intelligent ideology of managed energy-environment-society relations consonant with human development. The co-evolution of energy, environment and economic growth has resulted in synergistic development—a process of reinforcing development among energy, environment and economy and such synergism is now embedded in each other. Indeed, Energy system have underpinned and constructed deeply unequal social relations, as well as imbalanced nature-society relations, since the dawn of the fossil fuel era. More problematic, the causes and effects of energy consumption inequity have raised many questions for decision makers, One of them is that energy consumption has a distinct and critical social dimension. Whether it is truly an available process that the poor will catch up to the rich via energy-driven human development and the economies of developed and less developed countries will gradually converge. However, the effect of global warming on climate change is now more evident than ever before, with growing numbers of people and rising average levels of welfare it gets very crowded in the carbon space and the claims on it are growing rapidly[1], it is very important for human how to share that space and or efforts to stay within it. As Moriarty and Honney (2010) noted, changing development paths which deemphasize economic development and stress basic needs can make a major contribution to dwindle carbon space. They also propose a general "shrink and share" approach to reductions in both fossil-fuel use and carbon emissions, with basic human needs satisfaction replacing economic growth as the focus for economic activity. Especially for developing countries, replicating the development path of the developed countries with their heavy reliance on carbon-rich energy sources would amount to running into a dead-end street. Rather, these countries should choose more sustainable development paths. There is little discussion about the nature of the overall transition to more sustainable energy system based on human basic needs.

It will be critical in planning for the transition to understand the energy-society relations: how to improve the quality of life of developing countries based on available transition models of development that are related to meet basic human energy needs? The human development index (HDI) establishes the relationship among energy use, economic growth and social growth. When energy use is associated with HDI, it is possible to find opportunities to put into practice the synergistic development of energy and society, by looking for new conditions to shift the focus of the economy to satisfying basic human needs.

1 The concept "carbon spaces " was introduced by Opschoor Hans (2009), these are detailed in his article "Sustainable Development and a Dwindling Carbon Space".

Based on the welfare theories, to achieve higher human development each individual should enjoy development rights, including social, economic, political, as well as the basic survival needs and the provision of non-material services for the enjoyment of demand for the natural resources. Therefore, the concept of human development is important because it is not only concerned about the current state of the human well-being but about the realization of human potential as well. Each member of the society is entitled to realize their basic human right to development potential given constrained natural resources.

Focus on the high-income OECD groups with high human development levels and selected emerging countries with rapid progress of human development, the present paper will look at the phenomenon of "energy consumption transition" from an econometric perspective and estimate the catch-up elasticity of human development to energy consumption. Our paper makes some important contributions to the literature. First, we calculate the HDI from 1998 to 2007 of selected countries based on UNDP. It is composed of three parts including level of education, health as measured by the life expectancy at birth and real income as proxied by the GDP per capita PPP. HDI values are between 0 and 1, with high levels of human development being closer to 1 and low levels of human development being closer to 0. Second, and more important, we examine energy consumption convergence by means of a new methodology introduced by Phillips and Sul (2007, 2009). The methodology is based on a nonlinear time-varying factor model that incorporate the possibility of transitional heterogeneity or even transitional divergence. Moreover, the methodology is robust to the stationarity properties of the series under scrutiny, i.e. it does not rely on any particular assumption concerning trend stationarity or stochastic nonstationarity. In this way, we can examine the energy consumption relative transition curves for selected countries. Finally, we will estimate the catch-up elasticity of human development to energy consumption for these countries. In our analysis, two sources of data are used for our analysis, namely the UNDP dataset and the IEA dataset. HDI data includes three parts, longevity, education index is from the UNDP，GDP and energy consumption data is from the IEA.

2 LITERATURE REVIEW

The existing literature has established a positive relationship between energy consumption and economic growth as measured by GDP per capita, which is also used as a proxy for the standard of living. It is believed in the literature that standard of living and energy consumption are positively related and the higher the standard of living in a particular country, the higher is its consumption of energy. This relationship has been extensively studied for developed countries (Bowden and Payne, 2009, Narayan and Smyth, 2008, Huang et al., 2008) and has been a subject of the recent research for the less-developed countries (Apergis and Payne, 2009, Yuan et al., 2008, Lee and Chang, 2007). However, very little attention in the literature has been paid to the development indicators other than GDP, particularly HDI. This can be partly explained by the difficulties in terms of data availability. For instance, although the HDI index was developed in 1990, the UN undertook several major revisions of the index, so that the data from different years are not comparable over time and cannot be used as a single series.

To the best of our knowledge there are very few articles in energy literature, which discuss the relationship between HDI and energy consumption. These papers (Martınez and Ebenhack, 2008, Ediger and Tathdil, 2007, Dias et al, 2006 and Pasternak, 2000) provide a description of human development indicators and do not model the relationship between human development and energy consumption. Martınez and Ebenhack (2008) studied correlation between the HDI and per capita energy consumption for 120 nations. They found a strong relationship between index values and energy consumption for the majority of the world. They have also identified three important trends which emerged from the data: a steep rise in human development relative to energy consumption for energy-poor nations; a moderate rise for transitioning nations; and essentially no rise in human development for developed nations consuming large amounts of modern energy. Therefore, improvements in energy consumption can potentially lead to the large gains in human development for the world's poorest nations. Using Principal Component Analysis, Ediger and Tathdil (2007) recalculated the weights of the 2000 HDI data for 173 countries by integrating an energy component in the index. After comparing the modified index with other energy-related indicators provided in the UN Human Development Report 2003, they recorded severe differences in countries rankings. Dias et al. (2006) have provided a general discussion of the relationship between HDI and energy consumption based on the 1999 HDI and energy consumption data. They have calculated the energy consumption reduction potential for the developed countries with no significant life quality loss to help reduce the natural resource depletion. Pasternak (2000) studied the relationship between HDI and the consumption of energy and electricity using 1997 data. He found that HDI and per capita energy consumption are highly correlated and identified an electricity threshold for a maximum HDI. This threshold was used to estimate future global electricity consumption levels associated with high human development criteria up to 2020.

Meanwhile, traditional economic growth theories such as the Solow-Swan theory proposed by Solow (1956, 1957) and Swan (1956), and further developed by Meade (1961), suggest that economic progress is mostly determined by the capital investment and labour. The Solow model, in its original form, depends on only two independent variables, or 'factors of production' namely, total labor supply and total capital stock (Solow 1956, 1957). Labor and capital services are assumed to be proportional to their corresponding stocks.

However, economic growth in the industrialized countries has not slowed down to the degree suggested by Solow , while most developing countries (with some notable exceptions, as noted hereafter) have not been catching up in their development levels (Barro and Sala-I-Martin, 1995). Easterly and Levine (2001), having extensively reviewed the published literature of economic development studies, argue—as Solow did—that "something else" accounts for most of the observable differences between growth experiences in different countries. they . adopt the standard convention of referring to this "something else" as Total factor productivity or TFP. Thus, the empirical results are not conclusive. We propose to gain insights on convergence by suggestion a new theoretical approach to analyze the development differences.

The notion of convergence among countries is based on the assumption that these countries are initially in disequilibrium. Numerous papers discuss and debate on different kinds of convergence. In general, growth literature (and afterwards environmental literature) considers three different types of convergence: Beta convergence, Sigma convergence and Stochastic convergence. Durlauf and Quah (1999) and Durlauf, Johnson and Temple (2006) provide excellent overviews of this vast literature and the econometric methodology on which it rests. Phillips and Sul (2007, 2009) present a new panel data methodology that is particularly useful in measuring a transition towards a long run growth path or individual transitions over time relative to some common trend, either representative or aggregate. The methodology allows for both common and individual-specific components and is formulated as a nonlinear time-varying factor model. We will examine the convergence in energy consumption for selected countries by the means of this new methodology.

Furthermore, as Li and Ayres (2008) noted, the standard economic development theory up to now also shares a significant and even bizarre feature: it does not consider natural resource consumption and use to have any impact on the growth process. It seems to follow, of course, that the availability—or non-availability—of ever-cheaper fuels and sources of power will inevitably have a crucial impact on future economic development. It is simply not plausible that resource consumption is determined only by growth but not vice versa, or that GDP growth will continue indefinitely at a constant rate like manna from heaven. On the other hand, it is clear that human development does not automatically imply economic growth because performance of countries in terms of GDP growth can be very different from basic development indicators (Noorbakhsh, 1996; Costantini and Monni, 2005). Undoubtedly, human development and poverty eradication require sustainable development which needs fostering and improving human quality of life and wellbeing by integrating economic growth, human progress and environmental protection. Obviously, it is a right choice for human being to be able to articulate a sustainable, equitable and human development orientations society, it is profoundly unethical for developed countries with high human development levels to create a lifestyle that depends on a high level of energy consumption that developing countries cannot attain and that could not be sustained by the world's entire population. Therefore, we seek a hybrid variable to discuss the relationship of human development and energy consumption and estimate the path of developing countries catching up developed countries.

3 METHODOLOGY

In this section, we outline the econometric methodology we employ to examine the existence of convergence in energy consumption for selected countries. The methodology was introduced by Phillips and Sul (2007, 2009) in order to test for conditional sigma convergence in a panel of countries.

Suppose that Y_{it} is natural logarithm of energy consumption per capita for a panel of countries $i = 1, \ldots, N$ and $t = 1, \ldots, T$ where N and T are the number of countries and the sample size respectively. Y_{it} can be decomposed into the systematic and transitory components as follows

$$Y_{it} = a_{it} + x_{it} t \tag{1}$$

where a_{it} represent systematic components, including permanent common components that give rise to cross-section dependence, and $x_{it} t$ represents transitory components. For large value of t, Y_{it} eventually follows a long-run path that is determined by the term $x_{it} t$ in (1).

Philipps and Sul (2009) transform (1) in a way that common and idiosyncratic components in the panel are separated. Specifically,

$$Y_{it} = \left(\frac{a_{it} + x_{it} t}{\mu_t}\right)\mu_t = b_{it}\mu_{it} \tag{2}$$

where b_{it} or the individual transition factor explicitly measures the share of the common trend μ_{it} that country i energy consumption experiences. In general, the coefficient b_{it} measures the transition path of an economy to the common steady-state energy consumption path as determined by μ_t. This specification enables testing for convergence by examining whether the transition factors b_{it} converge to a constant, b by taking ratios instead of differences and thus eliminating the common growth component.

To do so, Philipps and Sul (2009) define the relative transition parameter, h_{it}, as

$$h_{it} = \frac{Y_{it}}{N^{-1}\sum_{i=1}^{N} Y_{it}} = \frac{b_{it}}{N^{-1}\sum_{i=1}^{N} b_{it}} \qquad (3)$$

which measures the individual transition factors for country i relative to the cross-section average energy consumption. Since h_{it} traces out an individual trajectory of energy consumption for each country relative to the average, it can be referred as the "relative transition path". Moreover, because, h_{it} measures country i's relative departure from the common steady-state energy consumption path μ_t any departures from μ_t are reflected in the transition paths h_{it}. These transition paths can be used to measure the extent of the departures and to assess whether or not the divergence from μ_t is transitory or permanent.

Assuming that there is a common transition behavior across countries in the panel (i.e. $h_{it} = h_t$ across all i), the ultimate energy consumption convergence or "the convergence of economy *i* to the steady state" (Phillips and Sul, 2009, p. 1159) energy consumption is given by

$$h_{it} \to 1 \quad \text{for all } i \text{, as } t \to \infty. \qquad (4)$$

This framework of energy consumption convergence allows to establish a family of relative transition paths, where the curves traced out by h_{it} may differ across individual countries in the short run, while allowing for ultimate convergence in energy consumption when (4) holds in the long run.

Figure 1 below shows four[i] different stylized transition paths (each satisfying the growth convergence condition (4)) after the common trend has been removed over the three transition periods. Phase A demonstrates initial convergence or divergence to the steady-state, Phase B is so called catch-up period and Period C shows final convergence to the steady-state. This figure shows that different economies will have different energy consumption transition paths depending on the "manner of economic transition and convergence" (Phillips and Sul, 2009, p. 1159). For example, while both relative transition parameters converge monotonically to unity, transition paths for Economies 3 and 4 have the same initializations with high initial states. Because higher energy consumption per capita typically corresponds to high HDI nations, Economies 3 and 4 could represent high income economies with high HDI values. Because of the faster convergence to unity throughout all three stages of development, Economy 3 could be characterized by potentially higher energy efficiency as compared to Economy 4. Economy 4 can be described by the initial divergence from the steady-state (transition Phase A) followed by the periods of catch-up (Phase B) and later (Phase C) convergence.

Transition paths for Economies 1 and 2 are the mirror image of that one for the Economies 3 and 4. Both paths involve transition from the same low initial state. Path for Economy 2 is typical of a HDI fast-growing country who's HDI grows with energy consumption. Transition path 1, is typical for a developing country that has a slow start at the initial phase (Phase A), begins to turn its economic and social performance around (Phase B) and then catches up and converges in consumption to unity (Phase C). It should also be noted, that although we have presented four transition paths, there can be an infinite number of possible transition paths, with different periods of transitional divergence even in cases when ultimate convergence has been reached (Phillips and Sul, 2009).

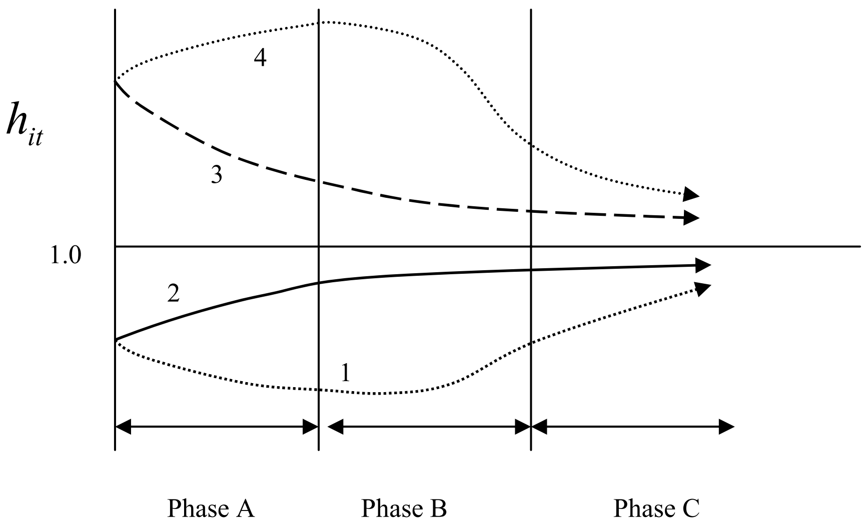


Figure 1: Relative transition paths h_{it} and phases of transition

(Source: modified from Phillips and Sul, 2009)

Furthermore, in cases of the ultimate energy consumption convergence, we have the limit $h_{it} \to 1$ for all i as $t \to \infty$, and then the mean square transition differential (H_t) converges to zero as $t \to \infty$ is shown in (5) below

$$H_t = N^{-1} \sum_{i=1}^{N} (h_{it} - 1)^2 \to 0 \text{ as } t \to \infty \quad (5)$$

To specify the null hypothesis of energy consumption convergence, Philipps and Sul (2007) implement the following semiparametric model for b_{it} :

$$b_{it} = b_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}} \qquad (6)$$

where b_i is fixed, ξ_{it} is i.i.d.(0,1) across i but may be weakly dependent over t and $L(t)$ is a slowly varying function (like log$t$) for $L(t) \to \infty$ which as $t \to \infty$. The parameter α denotes the speed of convergence, i.e. the rate at which this cross-sectional variation decays to zero. This representation ensures that b_{it} converges to b_i for all positive values of α (including the case when α =0). The null hypothesis of convergence is

$$H_0 : b_i = b \,\&\, \alpha \geq 0 \qquad (7)$$

The alternative hypothesis is given by

$H_A : \{b_i = b$ for all i with $\alpha < 0\}$ or $\{b_i \neq b$ for some i with $\alpha \geq 0$, or $\alpha < 0\}$

The role of the slowly-varying component *L(t)is to* ensure that convergence holds even when *α* = 0, albeit at a slow rate. The alternative hypothesis can accommodate both overall divergence or club convergence, i.e. the possibility that one or more subsets of the group of countries under scrutiny form convergent groups at different factor loadings, for example b_1 and b_2, but with positive rates of convergence. Under convergence, H_1 has the following limiting form as detailed in Phillips and Sul (2007, 2009)

$$H_t \sim \frac{A}{L(t)^2 t^{2\alpha}} \quad \text{as} \quad t \to \infty \qquad (8)$$

for some constant $A > 0$. Setting $L(t) = \log t$,brings the estimation of the following regression model:

$$\log(H_1 / H_t) - 2\log L(t) = a + \gamma \log t + \mu_t, t = [rT],...,T \qquad (9)$$

Specifically, this regression is run after a fraction (r) of the sample is removed. Phillips and Sul (2007) recommend setting values in the interval [0.2,0.3].

Under the null hypotheses of energy consumption convergence, the point estimate of the parameter converges in probability to the scaled speed of convergence parameter 2α .The corresponding *t*-statistic in the regression is constructed in the usual way using heterosckedasticity and autocorrelation consistent (HAC) standard errors.

Note that we are interested not only in the sign of the estimated coefficient $\gamma = 2\alpha$ in the log*t* model but also in its magnitude, which measures the speed of convergence of b_{it} to unity. Hence, if $\gamma \geq 2$ and the common growth component μ_t follows a random walk with drift or a trend stationary process, then large values of the growth component will imply convergence in level energy consumption per capita. However as noted by Phillips and Sul (2007) if $\leq \gamma < 2$, this speed of convergence corresponds to conditional sigma convergence. It is sigma convergence because tests for a decline over time in the cross-sectional dispersion of energy consumption per capita among different HDI groups of countries. But it is also conditional convergence, since it tests whether heterogeneous time varying idiosyncratic components converge over time to a constant after controlling for a common growth component among countries in the sample.

Compared with other exiting methodology, this one has many advantages, as noted by Panopoolou and Pantelidis(2009), this approach has the advantage of being suitable for asymptotic cointegration. The framework of this methodology accommodates cases where a long-run comovement in aggregate behavior exists irrespective of the existence of cointegration, and can be interpreted as an asymptotic cointegration test that does not suffer from the small sample problems of standard unit root and cointegration tests. More importantly, this methodology can still identify groups of countries that converge to different equilibria and at the same time allow individual countries to diverge.

4 EMPIRICAL RESULTS

4.1 HDI as a Proxy of human development

The main objective of human development, as stated in the Human Development Report of the United Nations Development Programme (UNDP), is to create an enabling environment for people to enjoy long, healthy, and creative lives. In this context, income and economic growth are means and not an end to development, and people's wellbeing depends on how income is used to achieve higher quality of living standards. UN analyzed various concepts raised in earlier development discussions and placed them in a comprehensive framework of human development that was defined as "a process of enlarging people's choices, the most critical ones are to lead a long and healthy life, to be educated and to enjoy a decent standard of living" (UNDP, 1990). Undoubtedly the HDI itself is clearly a reductionist measure, incorporating just a subset of possible human choices, additional choices include political freedom, guaranteed human rights and self-respect. These factors certainly differ widely across countries, and consistent time series data for these variables are scarce, in most cases, some factors are not available to measure. It is difficult to assess their impacts on human development. We therefore will look at a comparison between the HDI and these factors.

At first, in order to represent the political freedom and human right guarantee aspect of human development, we use CPI (national corruption index) and run a simple bivariate regression. Figure 2 shows a very robust relationship between the CPI and the HDI. One attractive interpretation of this regression is that it is something of a cross-validation of these two measures: both the HDI and CPI scores appear to be picking up related human development. In fact, we do not deny that human development is linked in some ways to democratization or that substantial changes in human development and democratization levels can lead to reductions in the levels of social conflict, in this sense that we think the democratization will persevere and make the whole world more harmony. Being an important measure of democratization, the level of a nation's CPI encompass to some extent its political freedom and human right guarantee. The higher CPI score is, the larger people's choice is. Given that cross-national comparisons of human development, we are certainly aware that other things than HDI can matter to human development.

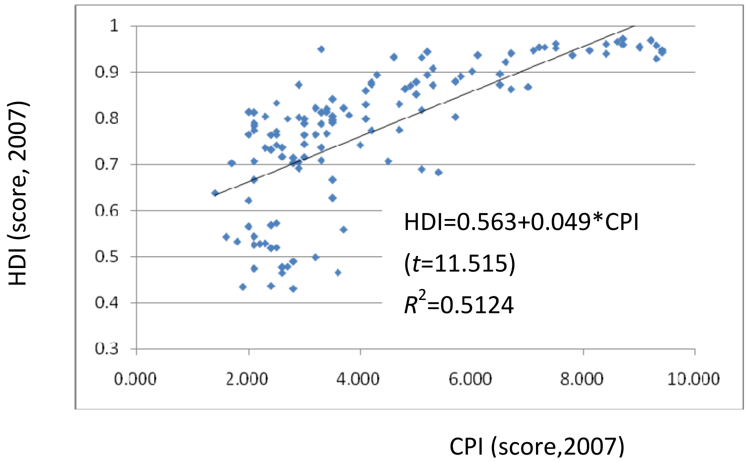


Figure 2 CPI and the HDI

As a further check on how well a nation's human development accords with other measures of human development, we check the relation between the Happiness Index of World Values Survey and the HDI. Figure 3 shows a more robust correlation between average responses to the Happiness question and the average of HDI. These data suggest that its citizens of a higher HDI nation are on average happier than others. Using the World Values Survey, We find a strong positive relationship between the HDI and the measure of happiness.

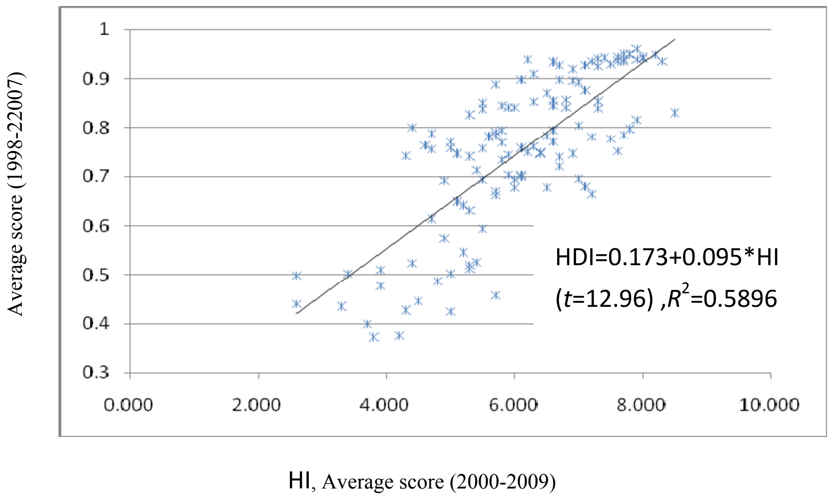


Figure 3 Happiness index and the HDI

In short, we can use the HDI as a proxy of human development to explain the relationship between energy consumption and human development. As some economists (Desai,1991; Naqvi,1995; Boozer et al., 2003) discovered, the HDI is able to capture, much more than GDP, people's real condition of life. Based on satisfying human's basic needs, we analyze whether or how human development are dependent on energy consumption.

Based on the Human Development Report (HDR)(UNDP,1990~2009) and the IEA dataset, we calculate the HDI of selected countries from 1998 to 2007. Table 3 shows the HDI values of selected countries.

Table 1: HDI values of Selected countries

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Australia	0.939	0.941	0.941	0.945	0.947	0.954	0.941	0.961	0.963	0.965
Austria	0.916	0.927	0.931	0.934	0.933	0.935	0.941	0.940	0.944	0.946
Belgium	0.931	0.939	0.939	0.943	0.942	0.946	0.940	0.940	0.943	0.946
Canada	0.942	0.921	0.941	0.929	0.942	0.945	0.947	0.955	0.958	0.959
Czech	0.852	0.851	0.855	0.864	0.869	0.874	0.878	0.884	0.890	0.893
Denmark	0.916	0.924	0.928	0.928	0.937	0.936	0.940	0.943	0.945	0.947
Finland	0.924	0.928	0.932	0.933	0.936	0.94	0.943	0.946	0.949	0.953
France	0.924	0.927	0.929	0.930	0.920	0.934	0.935	0.944	0.946	0.949
Germany	0.917	0.926	0.927	0.924	0.922	0.927	0.929	0.931	0.933	0.936
Greece	0.888	0.889	0.892	0.897	0.906	0.916	0.92	0.925	0.929	0.932
Hungary	0.822	0.831	0.836	0.840	0.847	0.860	0.860	0.865	0.869	0.871
Iceland	0.933	0.932	0.934	0.941	0.940	0.953	0.958	0.963	0.967	0.968
Ireland	0.913	0.917	0.923	0.927	0.928	0.937	0.946	0.953	0.957	0.961
Italy	0.912	0.915	0.918	0.918	0.919	0.930	0.936	0.939	0.943	0.943
Japan	0.928	0.928	0.931	0.933	0.936	0.939	0.943	0.946	0.949	0.951
Korea	0.856	0.875	0.879	0.885	0.890	0.901	0.908	0.921	0.927	0.931
Luxembourg	0.918	0.924	0.925	0.930	0.933	0.949	0.945	0.956	0.959	0.960
Netherlands	0.937	0.938	0.941	0.942	0.941	0.942	0.944	0.948	0.952	0.955
New Zealand	0.909	0.916	0.921	0.922	0.927	0.934	0.936	0.940	0.941	0.942
Norway	0.949	0.952	0.953	0.955	0.955	0.962	0.966	0.967	0.970	0.971
Portugal	0.869	0.875	0.879	0.893	0.894	0.900	0.897	0.891	0.892	0.895
Slovakia	0.833	0.832	0.833	0.832	0.838	0.845	0.850	0.857	0.863	0.870
Spain	0.910	0.914	0.918	0.921	0.922	0.929	0.933	0.934	0.937	0.940
Sweden	0.937	0.947	0.947	0.947	0.950	0.954	0.951	0.954	0.955	0.957
Switzerland	0.926	0.930	0.936	0.940	0.940	0.947	0.945	0.947	0.950	0.952
UK	0.927	0.931	0.934	0.934	0.938	0.939	0.934	0.938	0.936	0.939
USA	0.934	0.938	0.941	0.939	0.937	0.940	0.943	0.951	0.952	0.953
South Africa	0.698	0.700	0.691	0.670	0.660	0.653	0.644	0.684	0.686	0.689
China	0.713	0.718	0.727	0.722	0.745	0.756	0.764	0.774	0.782	0.790
India	0.565	0.573	0.576	0.581	0.591	0.598	0.604	0.611	0.619	0.627
Indonesia	0.673	0.676	0.681	0.684	0.689	0.692	0.705	0.724	0.730	0.735
Brazil	0.751	0.749	0.754	0.774	0.770	0.787	0.785	0.796	0.800	0.804

4.2 Energy Consumption Transition for High-income OECD Countries and Some Emerging Countries

Figure 4 plots the relative energy consumption per capita transition paths of six countries[2]. For the complete panel of countries, the transition paths do not tend to unity. However, it is also evident that USA, UK and Japan converge to the same steady state while Brazil, China and India converge to a different equilibrium.

[2] The country selection is mainly based on data availability. Due to the large number of countries considered in this study, a figure with all 105 transition paths would have been confusing.

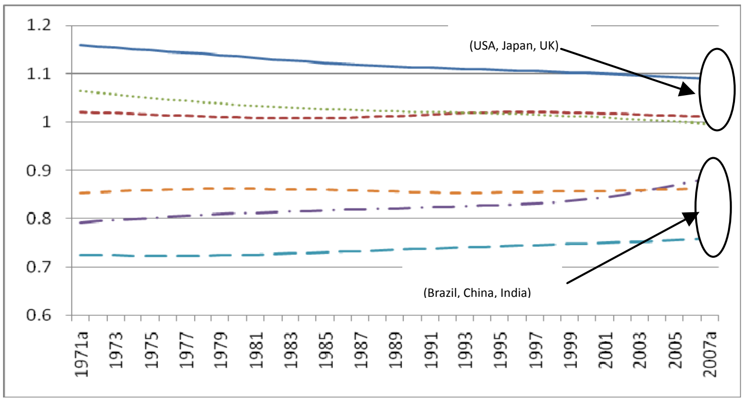


Figure 4: Examples of relative transition paths of selected 105countries (1971-2007)

According to Phillips and Sul (2007, 2009), under the assumption of convergence, the relative transition path tends to unity for all countries in the panel. As demonstrated on Figure 4 above, we can use(3) to calculate the relative transition paths, $h_{it,}$ for each selected country in the sample to examine the behavior of its energy consumption relative to the panel average. Figure 5 displays the relative transition parameters calculated for log per capita energy consumption in the 27 high-income OECD countries over the period from 1971 to 2007 after eliminating business cycle components.[3] Evidently, there is heterogeneity across countries, but also a marked reduction in dispersion of the transition curves over this period, together with some clear evidence that the relative transition curves narrow down towards unity.

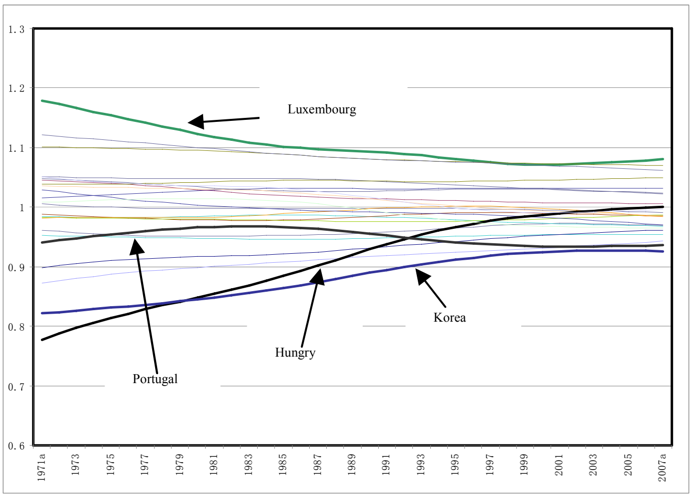


Figure 5: Transition path for High-income OECD countries

As a further illustration on the pattern of transition for high-income OECD countries, we check the relative transition curves for some countries against the benchmark of the USA (see Fig. 6 below). The patterns of transition for the higher income OECD nations are similar But some countries (e.g. Slovak Republic, Czech Republic) have some different stylized patterns. At the start of this period, all

[3] We used HP and trend regression methods to eliminate business cycle components and the results showed little sensitivity to the method employed.

the transition curves are similar in form to phase B until to 1984. From 1985 to 1997, the transition curves of some countries are similar in form to phase A (transitional divergence), and with evidence of the phase B turn-around coming towards the end of this period.

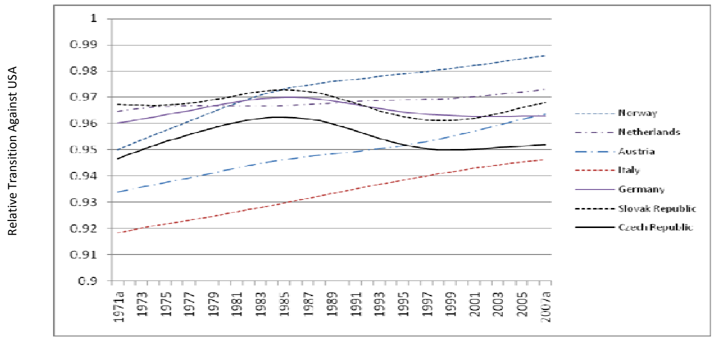
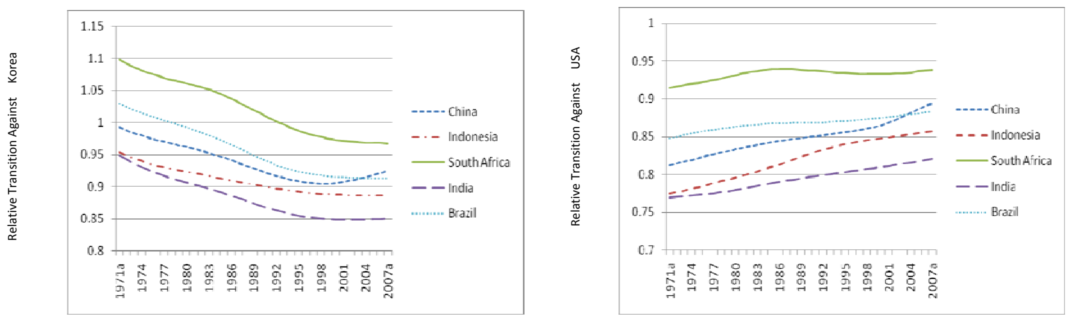


Figure 6: Examples of the high-income OECD countries relative transition against USA in per capita energy consumption

Sharing the Earth in a fair way require "convergence" of currently widely unequal per capita energy consumption. Assuming that the world human development are in transition to ultimate convergence on a path that is related to long-run historical OECD development, then we can expect that emerging countries (e.g. China, Brazil, India) will continue to develop faster over the next decade than the OECD nations as they experienced phase C transition. However, for developing countries to replicate the development path of the industrialized countries with their heavy reliance on energy sources would amount to running into collapse. We will look at how the emerging countries can catch up to the high-income OECD countries based on the relationship between human development and energy consumption.

For emerging countries, as indicated in the convergence criterion (4), the relative transition patterns are quite different from different benchmark. Figure 7 shows the relative transition curves for emerging countries BIICS (Brazil, India, Indonesia, China and South Africa) against the benchmarks of the USA, Korea, Japan respectively. Against Korea, the relative transition parameters seem to appear to diverge, however there is a noticeable narrowing in the transition curves towards unity against USA and Japan, indicating a clear tendency to converge. Meanwhile, they converge to the same steady state.



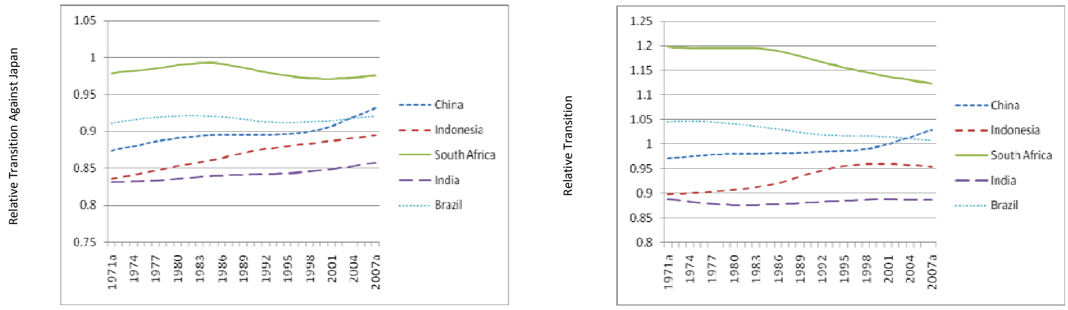
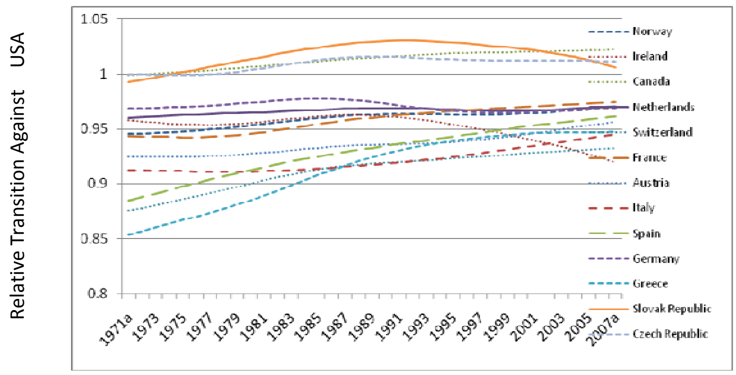


Figure 7: BIICS transition paths in energy consuption per capita

Compared with developed countries, developing countries have different patterns of energy consumption. At the same time, given the deep uncertainties in both future climate prediction and energy availability, it necessary to actively plan for a much lower energy future[4]. The two principle ways of reducing energy consumption are energy efficiency and improving energy conservation. Energy efficiency involves doing the same amount of work, or producing the same amount of goods or services, with less energy. Energy conservation involves using less energy regardless of the whether energy efficiency has changed. Developed countries have much higher levels of per capita energy consumption and at the same time, their energy intensity—energy consumption per dollar of GDP – is much lower than that of the developing countries. Improving energy efficiency is the same as or more available than reductions in per capita energy consumption for achieving the results of greatly cutting global energy use. Energy efficiency and conservation provide the best means to help foster replicable models of the good life or high human development levels that are based on much lower energy consumption levels in the short term (and the long term).

Figure 8 shows the relative transition curves in energy intensity for some developed countries against the USA, which is the largest energy consumer ion the world.The patterns of transition for these OECD nations are similar, but few countries (e.g. Ireland) have little different stylized patterns. At the start of this period, all the transition curves are similar in form to phase B until to 1990. From 1991 towards the end of the sample period, the transition curves of these few countries are similar in form to phase A (transitional divergence).



[4] Moriarty and Honnery (2010) evaluate the three possible technical approaches for climate mitigation: emission reduction methods, post-emission draw down of CO_2 from the atmosphere, and geoengineering. They find that the first two approaches are unlikely to deliver the timely reduction in CO_2 needed,while geoengineering methods either deliver too little energy or are too risky. Only by greatly cutting global energy use in a short time frame is ethical responsibility.

Figure 8: Examples of the high-income OECD countries energy intentity transition paths relative to USA

For BIICS countries, the relative transition patterns of energy intensity are quite different from different benchmark. Figure 9 shows the relative transition curves against the benchmarks of the USA, Korea, Japan respectively. Against Korea, the relative transition parameters seem to appear to diverge, however the transition curves tends to unity against USA and Japan, indicating a very clear tendency to converge. Meanwhile, they converge to the same steady state.

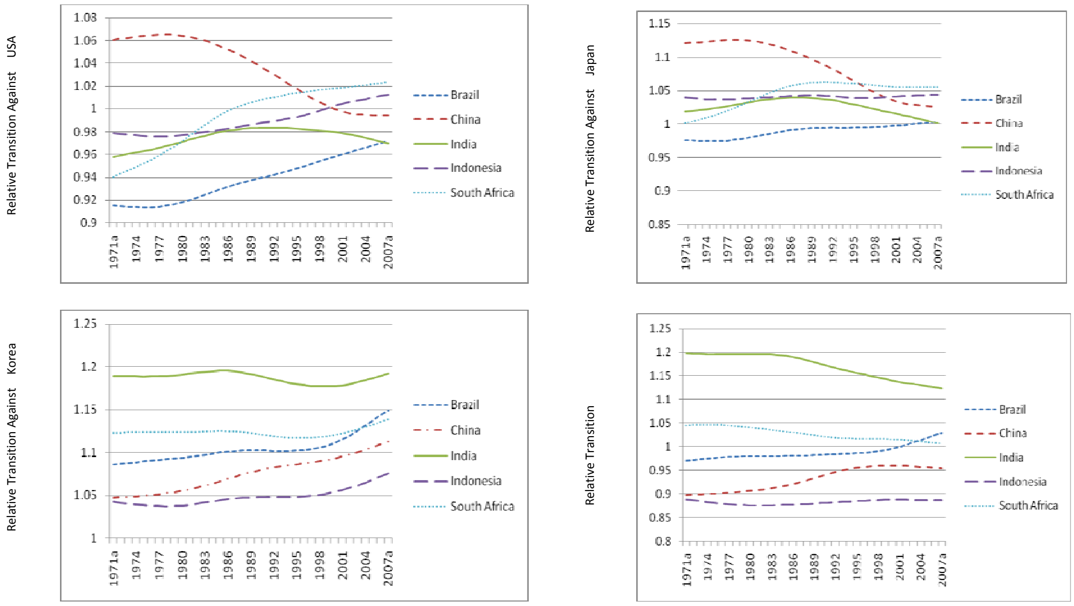


Figure 9: BIICS energy intensity transition paths

4.3 Convergence with Various Groups

We now employ the log *t*-test with the panels of per capita energy consumption for 105 countries, Group A, B, C (Group A includes 27 OECD countries, Group B includes five emerging countries with high levels of economic growth (Brazil, India, Indonesia, China and South Africa), and Group C includes all members of Group A and Group B) from 1971 to 2007. Table 2 reports the results of applying the log *t*-test with the four panel datasets.The last three columns in the table report the point estimates γ , the *t*-statistic and their standard errors.For the 105 countries and the Group C panels, there are no evidence of convergence: the poit estimates, γ, are significantly less than zero for all cases and the estimated stanard errors are so small for these cross-section groups that the null hypothesis of convergence is rejected even at the 0.1% level.

The second panel involves log per capita energy consumption for the Group A. The point estimate of γ =0.001596 is positive, but it is not significant. However, when we remove Iceland form the group, the point estimate of γ = 0.248741 , it is significantly positive (t-stat=9.677237, SE(γ)=0.025704), so that there is strong evidence in support of H_0 in (7) and for convergence as defined in(4). If the common stochastic trend component follows either a random walk with a drift or a trend stationary processes, then the speed of convergence parameter is significantly below 2, so that in the absolute level convergence can be rejected.

For the Group B, the log t-test indicates convergence in energy consumption between the five countries, however, sincevalue of γ are not large , the rate convergence is slow.

Table 2: Convergence tests for four panels

Cases	Time	γ	t-stat	SE(γ)
105 Countries	1971-2007	-0.624167*	-37.62322	0.016590
Group A	1971-2007	0.001596	0.036741	0.043447
Group B	1971-2007	0.093729*	3.752814	0.024976
Group C	1971-2007	-0.217210*	-30.86223	0.007038

Not: * Significant at the 1% level.

Furthermore, we examine other energy consumption index convergence with these various groups, the results are reported in Table 3. There is strong evidence of electricity consumption convergence for the three groups, since the estimated parameter of γ is statistically greater than zero.

For Group B, the log t test indicates convergence of all energy consumption indeces implying that BIICS countries converge towards a steady state. The null hypothesis of convengence of energy intensity and electricity intensity is rejected for the Group A. The relative transtion paths of energy intensity and electricity intensity do not tend to unity. For Group C, except the relative transtion of electricity consumption per capita, energy intensity and electricity intensuity paths diverge among the 32 countries in the group.

Table 3: Convergence tests of different energy consumption index for three groups

Energy index	Groups	γ	t-stat	SE(γ)
Electricity consumption per capita	Group A	0.103405*	5.552199	0.018624
	Group B	0.743766*	31.68734	0.023472
	Group C	0.154102*	9.006020	0.017111
Energy intensity	Group A	-0.369193*	-19.48485	0.018948
	Group B	1.026203*	14.99617	0.068431
	Group C	-0.142126*	-5.286377	0.026885
Electricity intensity	Group A	-0.593536*	-37.57546	0.015796
	Group B	0.304206*	15.15517	0.020073
	Group C	-0.491887*	-33.77357	0.014564

Not: * Significant at the 1% level.

4.4 Catch-up elasticity estimation

Human development is highly correlated with energy consumption(Martinez and Ebenhack, 2008; Dias et al., 2006; Pasternak, 2000). It is a very complex process for the developing countries to catch up with the developed countries via energy-driven human development policies, and it is probaly impossible to identify a set of necessary and sufficient conditions for human development .

Reduction in global energy consumption is crucial to a sustainable development process, low and medium human development countries can not imitate the historical experience of developed countries due to various resources constraints. Therefore, it is necessary for developing countries to increase energy demand in order to implement the potential growth in human development. On the other hand, sustainable development requires to achieve energy reduction targets and to improve energy efficiency and conservation on a global scale.

There is a big gap both between and within developing and developed countries in the human aspects of development and energy consumption. One of the objectives of this paper is to estimate the gap among the target countries and the leading countries. We now introduce a new variable – flexibility which shows the catch-up in human development and is defined as, the percentage changes in energy consumption with respect to HDI.

According to the results of aboved log *t*-test (see Table 2 ,Table 3), Group A can be referred to as “ the convergence club of energy(electricity) consumption per capita,” Group B can be termed “ the convergence club of energy consumption (include: per capita energy (electricity) consumption, energy (electricity) intensity)”, and Group C only can be termed “ the convergence club of electricity consumption per capita”. In our analysis, we assume the Norway is the “locomotive” of the Group A and Group C because its top HDI value , and that only countries that really were catching up should be used to generate the parameters for our model, the HDI or energy consumption fraction variable is the country’s HDI or energy consumption index ,as a fraction of the Norway in the same year. The larger the fraction, the smaller the gap with respect to the Norway. For Group B, we also assume that the Norway takes the leadship role in order to estimate developing countries catching up with developed countries in human development.

Based on the estimated catch-up trajectories (Figure 10) ,we now estimate two-non-linear models:

The natural logarithm model: $Y = a + bx + c\ln(x)$ (10)

The square root model: $Y = a + bx + cx^{\frac{1}{2}}$ (11)

where *Y* is the dependant variable (HDI fraction); *x*, is the independent variable (energy consumption index),also expressed as a fraction.

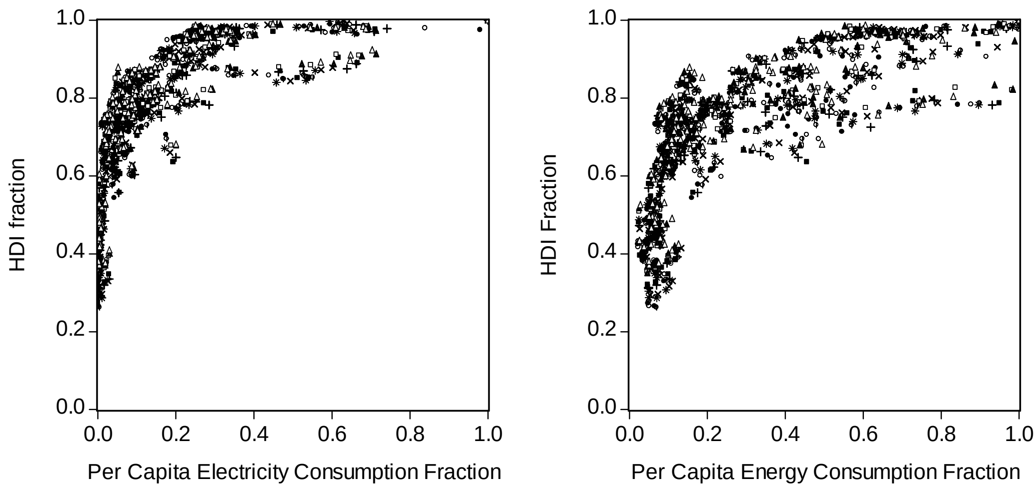


Figure 10 The catch-up trajectory

Based on these models, the catch-up elasticity of HDI to energy consumption which is necessary for the target nations to reach the value of the human development of the leading country (Norway) is calculated as

for the natural logarithm model: $dY / dx = b + c / x$ (12)

for the square root model: $dY / dx = b + 0.5cx^{-1/2}$ (13)

The simulation results of selected countries catch-up the Norway is shown in Tables 4 and 5. Figures 11 and 12 show the calculated catch-up elasticity trajectories of Groups A and B for the square root and natural logarithm models.

For Group A, the catch-up elasticity diminshes both with the increase of *x* and with the increase of *Y*. The catch-up elasticity decreases faster with the increase of *x* than the increase of *Y* at early human development stages and slows down at later development stage. A country's catch-up elasticity decrease to zero when its per capita energy consumption fraction reaches about 80% of the Norway level or per capita electricity consumption fraction reaches about 50%. In the natural logarithm model, A country's catch-up elasticity is estimated to be approximately 0.405, 0.246 and 0.150 when its per capita energy consumption fraction reaches 30%, 40% and 50% of the Norway level, which is similar in the square root model. However, the difference in catch-up elasticity of per capita electricity consumption is relatively small for all countries. In the natural logarithm model, A country's catch-up elasticity is estimated to be approximately 0.151, 0.057 and 0.01 when its per capita electricity consumption fraction reaches 30%, 40% and 50% of the Norway level.

For Group B, there is no obvious difference between the two values of per capita energy consumption and per capita electricity consumption for either model. A country's catch-up elasticity decreases fater with the increase of *x* than the increase of *Y* at early human development stages and more slowly at late development stage. A country's catch-up elasticity decrease to zero when its per capita energy consumption fraction reaches about 25% of the Norway level. In the square root model, A country's catch-up elasticity is estimated to be approximately 5.057, 2.394 and 0.511 when its per capita energy consumption fraction reaches 5%, 10% and 20% of the Norway level, also it is similar in the natural logarithm model. Similar to Group A, the difference in catch-up elasticity of per capita electricity consumption is relatively small for countries, In the natural logarithm model, A country's catch-up elasticity is estimated to be approximately 1.127, 0.619 and 0.366 when its per capita electricity consumption fraction reaches 5%, 10% and 20% of the Norway level.

Meanwhile, we simulate the catch-up elasticity of energy efficiency because it is very necessary for developing countries to be more energy efficient to achive improvement in improve human development, there is a big gap between developing countries and developed countries in terms of energy efficiency. Table 5 and Figure 12 show the results of the calculated catch-up elasticity of energy efficiency for Group B in both the square root and natural logarithm models, the leading country is also the Norway. As compared with other energy index, the simulation of catch-up elasticity in energy efficiency is different. At early human development stages, the catch-up elasticity is close zero, and then (energy efficiency fraction reaches about 75% of the Norway level) enhance with the improvement of energy efficiency. In the natural logarithm model, catch-up elasticity for every individual country is estimated to be approximately 0.204, 0.678 and 1.056 when its energy efficiency fraction reaches 80%, 90% and 100% of the Norway level, also it is similar in the square root model.

Table 4 : The results of the non-linear regression for the selected countries within Group A to catch up with Norway

Model / Parameter	$Y = a + bx + c\ln(x)$			$Y = a + bx + cx^{\frac{1}{2}}$		
	b	*c*	R^2	*b*	*c*	R^2
Per capita energy consumption[a]	-0.231330 (-4.331059)*	0.190798 (5.637521)*	0.40	-0.504321 (-4.727583)*	0.918633 (5.366943)*	0.39
Per capita electricity consumption[b]	-0.224331 (-8.623709)	0.112666 (11.10810) *	0.55	-0.529334 (-9.549939)	0.751517 (10.66660)*	0.53

Not: * Significant at the 1% level.

a, selected countries include: Ireland, Netherlands, Switzerland, Japan, France, Denmark, Austria, Belgium, Italy, New Zealand, Spain, Portugal, Korea, Greece, Israel, Germany and United Kingdom.

b, selected countries include: Australia, Ireland, Luxembourg Canada Sweden, Netherlands, Finland, United States, Switzerland, Japan, France, Denmark, Austria, Belgium, Italy, New Zealand, Spain, Portugal, Korea, Greece, Israel, Germany and United Kingdom.

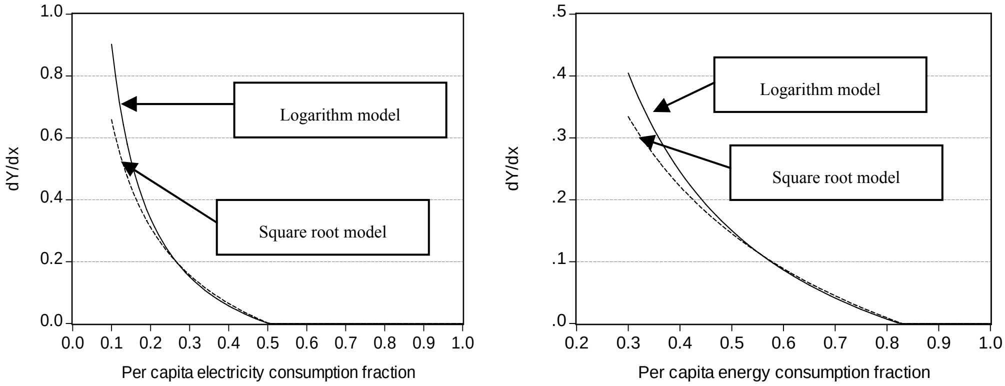


Figure 11: Group A human development catch-up elasticity of energy consumption trajectories

Table 5 : The results of the non-linear regression for the Group B countries to catch up Norway

Model / Parameter	$Y = a + bx + c\ln(x)$			$Y = a + bx + cx^{\frac{1}{2}}$		
	b	*c*	R^2	*b*	*c*	R^2
Per capita energy consumption	-1.793983 (-22.33969)*	0.435463 (24.29186)*	0.93	-4.034485 (-23.51935-)*	4.065663 (24.21938)*	0.93
Per capita electricity consumption	0.111779 (0.376184)	0.050747 (2.488127) *	0.61	-0.658373 (-1.085692)	0.834391 (2.452085)*	0.60
Energy efficiency	4.464216 (7.668576)*	-3.407800 (-7.973416)*	0.66	9.065581 (7.748302)*	-15.88176 (-7.892259)*	0.66

Not: * Significant at the 1% level.

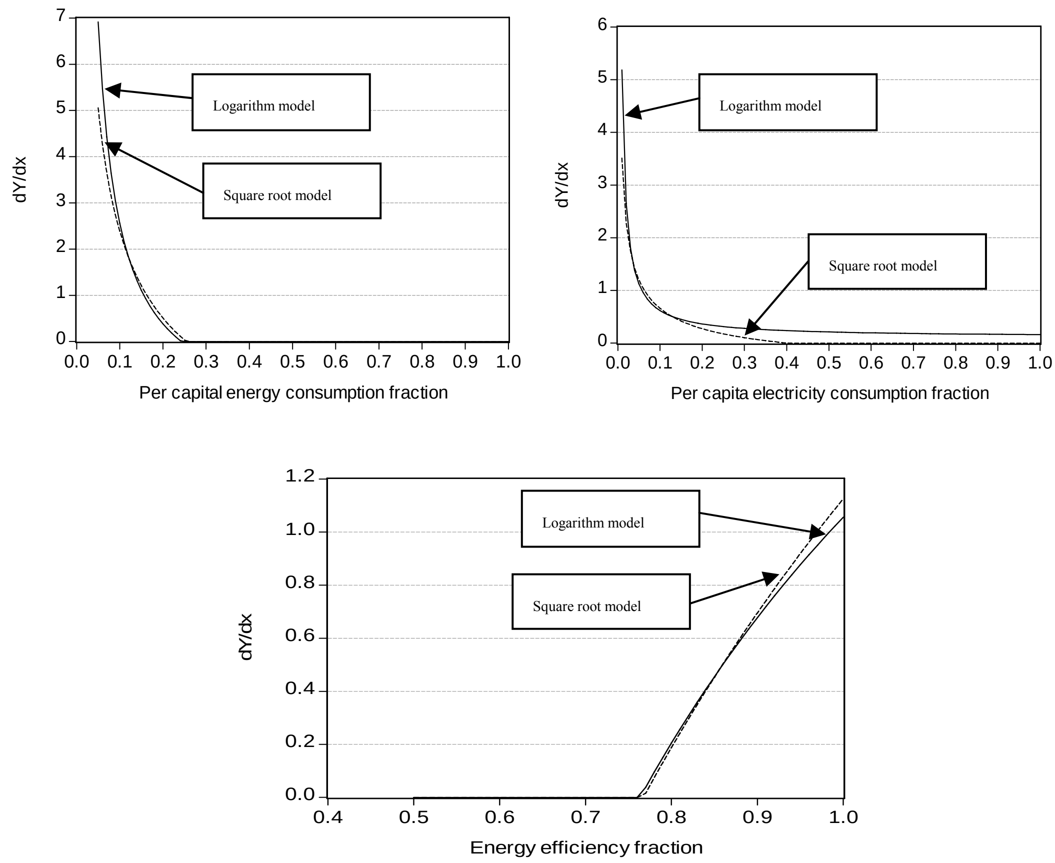


Figure 12: Curve of human development catch-up elasticity of energy consumption for Group B

5 . Conclusion

In mathematical terms, the impact of human impact on the Earth can be the equation may be respresented as function of population, per capita consumption and the current state of technology. The core message of this equation is that three factors contribute to our world impact, and more important sense is, no effort to reduce that impact is likely to succeed unless all three factors are addressed. This message has particular relevance to energy-related climate change, reduction in global energy consumption is crucial to a sustainable development process.

High-income countries should reduce their energy use through improvement in efficiency and conservation since they cannot continue to have an unfair and unsustainable share of the atmospheric commons. Instead they should help to develop and foster conditions of the good life that are based on much lower energy consumption levels. Developing countries to achieve higher human development levels cannot follow the path which has been established by the developed countries because it would require massive expansions in energy, transport, urban system and agricultural production all of which is unsustainable in a world of high resource constraints. This paper provides some insight on the energy consumption and energy intensity paths which are required for developing nations to catch-up with the developed based on a convergence tests introduced by Pillips and Sul (2007).

Compared to other methodologies, this approach incorporates the possibilty of transitional heterogeneity and it is robust to the stationarity properties of the series under scrutiny. The results suggest, there is ample empirical evidence that emerging countries such as the China, Brazil, India, Indonesia and South Africa (Group B) have shown convergence of all energy consumption index over the period from 1971 to 2007. For high-income OECD countries(Group A), the relative transition paths of energy intensity and electricity intensity do not tend to unity, but in energy or electricity consumption per capita, there is a clear tendency for these countries to converge. For all members of five emerging countries and 27 high-income OECD countries(Group C) in the sample, except for the relative transition of electricity consumption per capita, others indicate divergence among these countries. These three groups can be termed "the convergenc club of energy consuption".

Meanwhile, we assume the Norway is the "locomotive" of these groups because its top HDI value, and estimate the catch-up elasticty of energy consumption of other nations with respect to Norway. The results show that both the high-income OECD countries and emerging countries, at early human development catch-up stages the catch-up elasticity diminishes fast with the increase of the energy or electricity consumption per capita, and then stabilized, the value of catch-up elasticity between two groups is different. This would imply that in order to have improvements in the human development, a nation should not only rely on the increase in energy or electricty consumption, because it will work only in the short term. For emerging countries, the simulation results of catch-up elasticity in energy efficiency is different. At early human development stages, the catch-up elasticity is close zero, and then (energy efficiency fraction reaches about 75% of the Norway level) enhance with the improvement of energy efficiency, indicates that there is a big gap between developed countries and developing countries both HDI and energy consumption, it is true for them that energy-driven improvement in human development can continue indefinitely in the future.

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