Energy Economics 48 (2015) 24–31

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

# Energy distribution and economic growth: An empirical test for China

Robert J.R. Elliott [a], Puyang Sun [b,*], Qiqin Xu [b]

[a] Department of Economics, University of Birmingham, UK
[b] School of Economics, Nankai University, China

ARTICLE INFO

*Article history:*
Received 26 September 2013
Received in revised form 13 June 2014
Accepted 21 November 2014
Available online 29 November 2014

*JEL classification:*
O13
Q4
Q43
Q48
P28
P48

*Keywords:*
Energy
Electricity
Economic growth
China

ABSTRACT

In this paper we consider whether economic growth in China could be constrained by the physical development of the energy distribution network. Specifically, we structurally test the network theory of electricity distribution of Dalgaard and Strulik (2011) using city level data for China. In their paper they argue that the relationship between the size of the economy, measured by capital per capita, and electricity consumption per capita is governed by a simple power law with capital having an exponent bounded between ½ and ¾ depending on the efficiency of the network. We use data for 224 cities in China between 2002 and 2007 to observe whether structural estimates match those of Dalgaard and Strulik (2011) for 50 US states where they find the exponent in the power law connecting capital with electricity to be 2/3. Our results provide an estimate of the power law component to a little higher than the 2/3 found for the US which provides broad support for the model. When we look at different time periods we observe what appears to be a fall in the efficiency of the energy distribution network towards the end of our period.



## 1. Introduction

China's rapid economic growth in the last twenty years has been matched by an equally dramatic growth in the production and consumption of energy. A major concern for Chinese policymakers is whether the current rate of growth will be constrained in the future by physical constraints imposed by a shortage of energy distribution infrastructure. Central to this question is whether China's electricity distribution network will be able to continue to provide the electricity required by China's power hungry consumers and energy intensive manufacturing sector.

To shed some light on the relationship between energy distribution and economic growth we revisit a novel network theory of electricity distribution by Dalgaard and Strulik (2011). The model posits a supply relationship between electricity consumption per capita and the size of the economy measured by capital per capita where the economy is viewed as a transportation network for electricity. The logic is straight-forward. Energy is needed to run, maintain and create capital. Without an electricity supply, any investment in machinery at a particular place or time will not lead to economic growth.

Early attempts to model present how structural characteristics such as population growth and technological change affect the ability of an economy to accumulate capital (Domar, 1946 and Solow, 1956). The main contribution of Dalgaard and Strulik (2011) is to model the effect of complex electricity supply networks on economic growth using modeling techniques taken from biological sciences. A major innovation is the application of a power law association between consumption per capita of electricity and capital per capita with an exponent assigned to capital bounded between 1/2 and 3/4 with the final exponent dependent on the efficiency of the network. To capture instantaneous aggregate demand for electricity Dalgaard and Strulik (2011) employ an energy conservation equation with the result that they are able to provide a metabolic-energetic founded law of motion for capital per capita. A simple first-order differential equation looking at how capital per capita evolves over time allows them to study the implied dynamics and to be able to characterize the steady-state.[1]

The intuition is straight-forward. The greater the elasticity between consumption per capita and capital per capita the more efficient the

* Corresponding author at: Room 1405, School of Economics, Nankai University, Tianjin, China, 300071

*E-mail addresses:* r.j.elliott@bham.ac.uk (R.J.R. Elliott), puyangsun@nankai.edu.cn (P. Sun).

[1] The association between energy and growth is not new. The ability to harness energy for the betterment of society and how efficiently it can be deployed was first mentioned by the first principles of Spencer (1862) (Dalgaard and Strulik, 2011). To prevent "limits to growth" as a result of energy shortages will require technological change even if the supply of energy increases. The distribution of energy through a network is therefore crucial.

http://dx.doi.org/10.1016/j.eneco.2014.11.016
0140-9883/

network should be. This in turn should mean more electricity is available for final use and hence capital should be accumulated at a greater speed than it would be for countries with less efficient networks. If, as Dalgaard and Strulik (2011) assumes, that economies are operating at the boundary of physical feasibility, then their model should be testable using data on energy consumption per capita which is directly measureable. When they estimate their model structurally using data for 50 US states from 1960 to 2000 they find that the data fits the model well with a point estimate for the power law linking electricity and capital of 2/3. In addition they find evidence of some $\beta$-convergence in electricity consumption per capita across US States.[2]

The contribution of this paper is two-fold. First, we want to see whether the structurally estimated point-estimate for the power law of Dalgaard and Strulik (2011) holds for a different country to the US but also at a different level of aggregation. In this case we use a panel of 224 Chinese cities for the period 2002 to 2007 instead of US states. Second, we want to better understand the relationship between electricity networks and economic growth in China and how the efficiency of China's electricity network compares to that of the US.

The result of our examination of growth in electricity consumption per capita and associated structural test for China reveals that the data for the model reasonably well with a power law linking electricity and capital a little above 2/3. This suggests that China's energy networks for cities are at least at efficient as those for US states and are arguably more efficient allowing China to accumulate capital at a faster rate. This good news is mitigated by the finding that the efficiency of China's network, although generally good, shows signs of deterioration in recent years no doubt as a result of China's rapid growth straining existing electricity distribution networks. Overall, China appears to have done a remarkably good job in maintaining the electricity supply to industry although our results suggest that such a performance may be difficult to maintain if China's rate of urbanization and growth continues.

The remainder of the paper is organized as follows: Section 2 briefly outlines the model of energy distribution and economic growth of Dalgaard and Strulik (2011). Section 3 provides a brief overview of China's electricity network during the period 2002 to 2007. Section 4 discusses our empirical strategy while Section 5 presents our empirical results. Section 6 concludes.

## 2. Theoretical background

Research in the natural sciences by Banavar et al. (2002, 1999) and West et al. (1997, 1999) model the energy distribution network as a living organism to verify a statistical finding in biology known as Kleiber's Law.[3] Dalgaard and Strulik (2011) took this concept and were the first to include something as complex as an electricity distribution network into a macroeconomic model. They argue that applying theories relevant to biological organisms to man-made electricity networks is a valid approach for three reasons. First, that cardiovascular system operates in a similar way to an electricity network by ensuring the distribution of nutrients and electricity respectively around a network. Second, man-made and biological networks are likely to share similar aggregate properties because of the process of development over time as the systems optimize through natural selection in the case of a biological network and constant reworking and upgrading in the case of man-made networks. Third, physicists are applying empirical methods from biological organisms to search for universal scaling laws that will impact on human society. The constant pressure to move to the optimal distribution network means that biological and man-made networks can be expected to share certain characteristics.

Taking electricity consumption per capita ($e$) to be the equivalent to metabolism and capital per capita ($k$) to be equivalent to body mass, the assumption is that the relationship between capital and electricity is concave and log linear. Dalgaard and Strulik (2011) show how electricity is made available at geographically dispersed sites through the self-organization of an economy. At first, they derive a model depicting characteristics of an energy distribution network from the supply side and draw a basic criteria about the relationship of energy consumption per capita and capital per capita. They state that the energy circulating in the network is different from the energy required by the capital equipment connecting to this network. Banavar et al. (1999) present examples of how networks can be designed to best serve electricity demand which we replicate in Fig. 1. It is assumed that electricity is generated at a power plant and then distributed via an electricity grid to end users via sites where the distance between a site and the source depends on how many other transfer sites the electricity has to pass through. The most efficient network is when there is a single path to source $i$ as the electricity in each path can be used to operate machines at these sites. Hence, shortages in the provision of electricity may be due to network inefficiencies as well as the demand for electricity of the machines within the network. Likewise, as capital increases, new transfer sites are required and the network then expands.

And eventually, given a strong assumption that total energy consumption is proportional to population,[4] electricity consumption per capita $e(t)$ should be log-linear correlated to capital stock per capita $k(t)$ at any given time t:

$$\begin{aligned} e &= \varepsilon k^{a} \\ a &\equiv \frac{D}{D+x},\ x \in [1, D]. \end{aligned} \tag{1}$$

Parameter $D$ in this model is equal to 3 for a sense of three dimensional space. Note that the parameter $x$ is the measure of the efficiency of energy distribution network which is a crucial benchmark to judge whether an economy is able to afford further economic growth.

Given the relationship between capital per capita and energy per capita, Dalgaard and Strulik (2011) further investigate this nexus from the perspective of energy demand. They argue that the demand for energy comes from the requirement of capital operation, maintenance and generation. The steady-state value of energy consumption per capita and capital per capita are given as:

$$\begin{aligned} k &= k^{*} \equiv \left[\frac{\mu + n v}{\varepsilon}\right]^{1/(a-1)} \\ \dot{e}(t) &= \frac{a\varepsilon^{1/a}}{v} e(t)^{2-1/a} - a\left(\frac{\mu}{v} + n\right) e(t). \end{aligned} \tag{2}$$

In addition to predicting a power law relationship between consumption per capita and capital per capita the model also makes predictions about the size of the elasticity between capital and energy consumption and argue that it should fall between ½ and ¾ depending on the efficiency of the network. The implication is that more efficient networks will allow a country or region to accumulate capital and hence grow at a faster rate in the future. Although they derive a steady-state Dalgaard and Strulik (2011) are quick to point out that technological change is one of the main drivers for pushing the physical limits of electricity production.[5]

[2] There has been a little written about the social impact of networks. Bettencourt et al. (2007) find evidence of a scaling law between city size and city development such as patents, employment and growth rates. They conclude that a city must have a continually accelerating innovation rate to support local economic development because of different mechanisms of material production and citizen welfare.

[3] Kleiber's Law was named after Max Kleiber's research in the early 1930s when he observed that for the vast majority of animals that the three-quarters power of body weight was the most reliable method for predicting the basal metabolic rate (BMR).

[4] Kühnert et al. (2006) use cross-sectional German city data to confirm this association and Bettencourt et al. (2007) find similar evidence from a sample of Chinese administrative units. Dalgaard and Strulik (2011) confirm this relationship using their US State data. We test this assumption empirically in our empirical section.

[5] A detailed discussion and exposition of the model can be found in the original paper of Dalgaard and Strulik (2011).