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Energy distribution and economic growth☆

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ABSTRACT

This research examines the physical constraints on the growth process. In order to run, maintain and build capital energy is required to be distributed to geographically dispersed sites where investments are deemed profitable. We capture this aspect of physical reality by a network theory of electricity distribution. The model leads to a supply relation according to which feasible electricity consumption per capita rises with the size of the economy, as measured by capital per capita. Specifically, the relation is a simple power law with an exponent assigned to capital that is bounded between 1/2 and 3/4, depending on the efficiency of the network. Together with an energy conservation equation, capturing instantaneous aggregate demand for electricity, we are able to provide a metabolic-energetic founded law of motion for capital per capita that is mathematically isomorphic to the one emanating from the Solow growth model. Using data for the 50 US states 1960–2000, we examine the determination of growth in electricity consumption per capita and test the model structurally. The model fits the data well. The exponent in the power law connecting capital and electricity is 2/3.

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1. Introduction

The work of Domar (1946) and Solow (1956) marked the beginning of the formal analysis of the growth process where physical capital accumulation is seen a key growth engine. This body of research has unveiled fundamental structural characteristics which impinge on the determination of labor productivity in the long run: savings, population growth, technological change and more. These factors share the common feature that they importantly affect the ability of an economy to mobilize resources for the purpose of capital accumulation.

At the same time, the basic neoclassical growth theory abstracts from the fact that it makes little sense to acquire a piece of machinery, at a particular time and place, unless the machine can be supplied with electricity and put to use. Surely, it is of first order importance that an economy is able to *distribute* electricity across the economy to the sites where investments are deemed profitable.[1] Omitting the *physical* preconditions for growth may be highly problematic as such factors can represent a binding constraint on economic growth. Hence, in the present study we provide an attempt to model electricity distribution, and take a first step towards examining its implications for the growth process.[2]

Electricity networks are highly complex systems; too complex, one might think, for macroeconomic modeling. Fortunately, progress has been made in the natural sciences in describing and modeling the aggregate properties of similarly complex networks. The work of West et al. (1997, 1999) and Banavar et al. (1999, 2002) is a case in point. By modeling biological organisms as an energy distributing networks these authors have been able to show, in keeping with the evidence, why the energy needs of an organism as a whole rises with the size of the organism in accordance with $B = B_0 \cdot m^b$, where B is basal metabolism, m is body mass, B_0 is a constant, and $b = 3/4$.[3] In the present context one might wonder if a similar sort of result could be derived in the case of an electricity network, thus linking electric power consumption and a measure of the "size" of an economy, such as the capital stock.

At first it may seem far-fetched to believe that empirical laws and mathematical theories pertaining to biological organisms should have any sort of bearing on man-made networks. But upon reflection the link is perhaps not improbable, for three reasons.

First, the cardiovascular system and the power grid share the feature of being energy distributing networks (of nutrients in the former case, electricity in the latter). Conceptually they are therefore highly related. Of course, the networks are very different at the more detailed level: in appearance and in terms of the matter being distributed. Nevertheless, and in spite of being developed for the investigation of biological systems, the inventors of the network theory that we employ to the study of electricity distribution below suggest themselves that their theory could be adapted to the case of electrical currents (Banavar et al., 1999, p. 132).

Second, there is a good reason why biological networks and man-made networks would come to have similar aggregate properties. Both biological and man-made networks are developed over time through a process of gradual optimization. In the former case this occurs through natural selection; in the latter it is the result of deliberate decisions to rework, extend and improve the efficiency of the network in question. Undoubtedly, the process of natural selection has worked to produce efficient networks. Quite possibly, man-made networks have moved in a similar direction. As efficient networks have certain unique properties (e.g., minimal transmission losses), biological and man-made networks should have some aggregate characteristics in common.

[1] Empirically, the close link between electricity and growth is well documented. For instance, in Henderson et al. (2009) the authors propose to use satellite data on lights at night as an alternative proxy for GDP.

[2] The present analysis is therefore related to the literature on infrastructure and economic growth. The traditional approach essentially consists of adding another input into the production function, thus capturing infrastructure capital (e.g., Arrow and Kurz, 1970 and many others since). Our approach to model the influence from the electricity infrastructure will differ in that we will provide a model for the network itself, and derive the critical associations between electricity use and capital. At the same time we abstract from other dimensions of infrastructure, like roads, ports, etc. Also, we abstract from the problems associated with the production of electricity, which in practise requires the use of natural resources. See e.g. Stiglitz (1974) and Suzuki (1976) for a discussion of sustainable growth in the presence of exhaustible natural resources.

[3] This formula is known as "Kleiber's law" (Kleiber, 1932), which, remarkably, holds across biological organisms spanning 27 orders of magnitude in mass; from the molecular level up to whales (West and Brown, 2005).