Charlie Wilson[1]

A COMPARATIVE ANALYSIS OF SCALING DYNAMICS IN ENERGY TECHNOLOGIES

[1] London School of Economics, UK, +44-207-955-6777, c.wilson1@lse.ac.uk

OVERVIEW

The 20th century has witnessed extensive diffusion of many supply-side and end-use energy technologies as part of a wholesale transformation of the energy system. Whole industries have grown, but so too have the size of technologies at the ‘unit’ level (e.g., the rated capacity of a steam turbine or a car engine). Analysing these historical growth dynamics at both industry and unit level reveals some general patterns that appear robust across very different energy technologies. Firstly, increases in the unit size of a technology generally comes after a period of experimentation with many smaller-scale units. This is particularly the case for technologies like nuclear or wind power with clearer economies of scale at the unit level. Secondly, the main growth phase of an industry takes place during, and then after the increases in unit size. Thirdly, the extent to which an industry grows is consistently related to the time duration of that growth. These findings have important implications for policy, not least in striking a cautionary note on pushing for significant jumps in unit size before a ‘formative phase’ of experimentation with smaller-scale units. This seems to be particularly relevant to emerging technologies such as carbon capture and storage.

METHODS

Unit and industry level time series data were collected for both supply-side technologies (refineries, coal power, nuclear power, natural gas power, wind power) and end-use technologies (jet aircraft, cars, compact fluorescent light bulbs or ‘CFLs’). All data were expressed as MW capacities, specifically: cumulative total capacity at the industry level; and average or maximum capacity at the unit level.

Comparisons of these data on unit and industry scaling across technologies need to account for changes in growth characteristics over the course of a particular technology’s lifecycle. Logistic growth models were fitted to the time series data subject to a goodness of fit criterion (adjusted R^2>0.95) and a reliability criterion (historical data covers at least 1-60% of the full extent of diffusion, i.e., reaches >60% of the estimated asymptote parameter, K). Two model parameters were then used to compare scaling dynamics between technologies:

- K (saturation level or asymptote): a measure of the *extent* of scaling;
- Δt (diffusion time from 10% to 90% of K): a measure of the *duration* of scaling.

RESULTS

The comparative analysis of energy technologies focused on the time sequencing of unit and industry level scaling, as well as the relationships between the extent and duration of scaling represented by the logistic model K and Δt parameters. Three key patterns were observed, robust across the range of energy technologies considered. Firstly, increases in the unit size of a technology generally comes after a period of experimentation with many smaller-scale units. This is particularly the case for technologies like nuclear, wind, and coal power (see Figure 1) with clearer economies of scale at the unit level. Secondly, the main growth phase of an industry takes place during and then after the increases in unit size. Thirdly, the extent to which an industry grows is consistently related to the time duration of that growth.

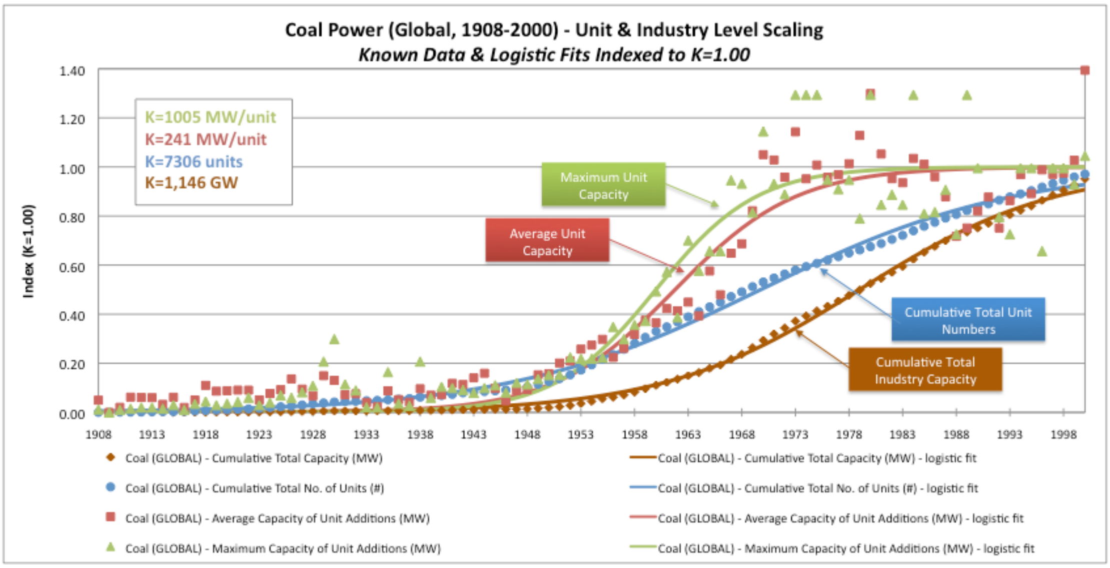

Fig. 1. Sequence of unit scaling & industry scaling: coal power (global). Curves are logistic models fitted to actual data and normalised so that each asymptote, K, =1 (absolute K values shown in the boxes).

CONCLUSIONS

The growth of energy technology industries comprises a ‘formative’ phase, then a ‘scaling’ phase that precedes or is concurrent with the main phase of industry growth. The ‘formative’ phase involves many smaller-scale units with only small increases in unit size. The subsequent ‘scaling’ phase sees large increases in unit sizes, particularly at the scale frontier, and a large increase in numbers of units. Importantly, the meta-analysis shows that *experimentation* with many smaller-scale units tends to precede substantive increases in unit size. The formative phase which follows an energy technology’s introduction into the market describes an often lengthy process of testing and experimentation with small-scale units that allows technologies to be ‘debugged’ through experience. These learning effects result in cost and performance improvements, but also facilitate the subsequent capture of unit scale economies as the industry matures. This offers a cautionary note for policies promoting significant jumps in unit size before a ‘formative phase’ of experimentation and learning with smaller-scale units. This is particularly relevant to emerging technologies such as carbon capture and storage.