CHAPTER 8

Technological Substitution and Long Waves in the USA

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8.1. Introduction

The analysis of historical replacement of old by new technologies has shown that most of these processes can be described by simple rules that are captured in the logistic substitution model (see Marchetti, 1979; Marchetti and Nakicenovic, 1979; Nakicenovic, 1984), and that technological substitution, expressed in terms of market shares, follows characteristic S-shaped curves. In order to illustrate and describe the properties of the approach we first give examples of how new energy forms replaced their predecessors, since technological changes in the energy system constitute one of the first and most complete applications of logistic substitution analysis. To further explore this method we then describe similar substitution processes in steel production and the merchant marines.

The application of the logistic substitution model to the above examples indicates that improvements and growth are achieved through a regular but discontinuous process. Each new technology goes through three distinct substitution phases: growth, saturation, and decline. This regular pattern points to a certain schedule and recurrence of structural change in competitive markets. The structural change in the above examples occurred at intervals of about 50 years.

The recurrence of changes every 50 years resembles the long-wave fluctuations in economic development originally described by Kondratieff (1926). One of the most extensive explanations of the long wave was given by Schumpeter (1939), for whom innovations come in clusters and are not evenly distributed or continuously absorbed, due to the basic principles that govern the

T. Vasko (ed.), *The Long-Wave Debate*

process of capitalist development. The clustering of technological and entrepreneurial innovations leads to the periodic emergence of new industries and subsequent growth, but this growth necessarily leads to limits and eventual decline. Thus, wave-like forms of economic development are generated with phases of growth and senescence at intervals of about 50 years.

A hypothetical relation between the 50-year period in the introduction of new technologies and saturation of old ones, and the 50-year period in the changing phases of growth and decline that is associated with the long wave must be verified empirically before the exact nature of the two phenomena connected with the process of technological change can be related to each other. This analysis essentially consists of the use of a phenomenological approach to extract long fluctuations from the time series in an attempt to filter out the long-waves and to compare the fluctuation patterns thus derived with the dynamics of technological substitution. The changing phases of the long-wave fluctuations are illustrated with the same examples as those for technological substitution: energy consumption, steel production, and the merchant marine fleet.

All of the examples illustrate the American experience. Thus, while the results are equivalent to similar examples for some other industrialized countries and the whole world, it is inconclusive whether they may also be of a more general nature. Unfortunately, historical data cannot be reconstructed from available records for too many different cases, although the UK has been analyzed with equivalent examples. All of the reported examples and historical data for the USA (and also the UK) are given in Nakicenovic (1984).

8.2. Technological Substitution

Substitution of an old way of satisfying a given need by a new path has been the subject of a large number of studies. One general finding is that substitution of an old technology by a new one, expressed in fractional terms, follows characteristic S-shaped curves. Fisher and Pry (1971) formulated a very simple but powerful model of technological substitution [1].

8.2.1. Primary energy consumption

The analysis of the competitive struggle between various sources of primary energy has been shown to obey a regular substitution process that can be described by relatively simple rules (Marchetti, 1977; Marchetti and Nakicenovic, 1979; Nakicenovic, 1979). The dynamic changes in this process are captured by logistic equations that describe the rise of new energy sources and the senescence of old ones. *Figure 8.1* shows the primary energy consumption in the USA since 1850; data are plotted on a logarithmic scale and show exponential growth phases in consumption of the most important sources of primary energy by piecewise linear secular trends. Thus it is evident that energy consumption grew at exponential rates during long time periods, but