Socio-technical evolution

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Introduction

Are we evolving into a new Post-Industrial epoch driven by the emerging living and intelligent technologies, spearheaded by the digital revolution? Or are we just entering a new period in the Industrial epoch, where we don't need to radically update our institutions, the market and our cultural narratives? Using an evolutionary perspective and time series analysis we seek to investigate these questions.

We report a study of the long term dynamics of the economy across 28 countries and across different socio-technical epochs, some dating back to 1270, while others starting at the onset of the Industrial Revolution. Using standard time series analysis methods we report overall growth dynamics as well as rhythmic phenomena in the growth patterns after the onset of the Industrial Revolution. Our main data sources include the Maddison Project [4], Edvinson [1], Our Wold in Data [7] and updated data references in the cited literature. Assuming these evolutionary changes of our societies are driven by fundamental inventions that are capitalized through innovation when the socio-economic climate is appropriate (Mensch) [5], we can use a simple mathematical model (Mosekilde et al.) [6] to interpret and to better understand the underlying dynamics for the empirical data as well as provide informed, tentative forcasts for the future (Rosenlyst et al.) [9].

The Agricultural and the Industrial epochs

It is easy to detect the difference between the aggregated economic dynamics for the agricultural and the industrial epochs. In Figure 1 the gross domestic product per capita (GDP/cap) for England (UK£) $f_E(t)$ and Sweden (SEK) $f_S(t)$ are shown partially detrended as $\log(f_E(t))$ and $\log(f_S(t))$. These two epochs are characterized by both different technologies and different societal organizations. The result is that the pre-industrial epoch is characterized by economic stagnation while the industrial epoch is charcterized by sustained economic expansion. During the Agricultural epoch there is no significant difference between the lives of successive generations. Since the socio-economic system is close to steady state, the economy can be viewed as a zero-
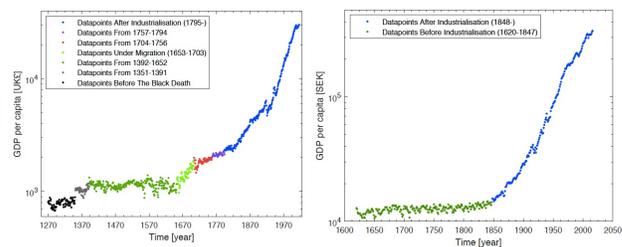

Figure 1: **Left panel:** Log-linear GDP/cap for England 1270-2016 in 2013 British Pounds [7]. The blue data points indicates industrialisation. **Right panel:** Log-linear GDP/cap for Sweden 1620-2016 in 2000 Swedish Krona [1]. The blue (green) data points are after (before) industrialisation.

sum game, which is e.g. clearly seen in the English data for the period after the Black Death swept through the country, where almost half of the population died. As a result the survivors became more prosperous. In the industrial epoch the economy is no longer in steady state.

Growth rhythms in the Industrial epoch

To investigate the more subtle dynamics in the evolution of the economy since the onset of the Industrial Revolution, the time series have to be detrended further for this period. From Figure 1 we can see that removing a linear trend from the logarithmically transformed data is not sufficient to obtain a stationary time series. Subtracting a second order polynomial trend from $\log_X f(t)$ provides stationary series for all 28 countries, of course with different polynomial coefficients. These stationary time series are now further investigated for possible dominating periodicities through Fourier analysis.

Based on the analysis of the 28 Industrial economies all countries can roughly be divided into two groups. One group (Group 1) includes most countries in Europe, North America, Australia, New Zealand and the other countries connected to the Western World as Japan and Brazil. Group 1 is characterized by a general decline in the relative economic growth since the 1970s. The other group (Group 2) includes some countries in Asia and South America as India, Sri Lanka, Chile and Argentina. Also Russia belongs to
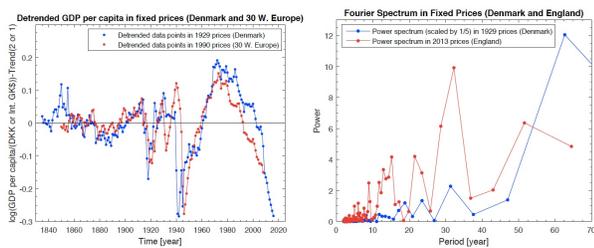
Figure 2: See text for details. **Left panel:** GDP/cap for Denmark [8] (blue curves) and 30 EU countries [4] (red curves) in current prices exponentially and parabolically detrended. **Right panel:** The Fourier spectrum as a function of period for Denmark [8] (blue curves) in 1929 prices and England [7] (red curves) in 2013 prices (GDP/cap) exponentially and parabolically detrended. Note the ~ 30 year top for England (Kuznets) and the ~ 60 year top for Denmark (Kondratieff).

this group. Group 2 is characterized by a general increase in the relative economic growth rate in recent years. We have not been able to obtain reliable data from China. Group 1 can further be divided into two major subgroups: (1a) the US and (1b) the EU with the rest of Group 1, except England that is in between. This division is based on the detected dominating growth rhythm in the empirical data for GDP/cap in fixed prices. The EU subgroup has a dominating growth rhythm of 50-65 years, while the US has a dominating growth rhythm of 25-35 years, Kondratieff [2] and Kuznets [3] waves respectively, named after the economists that initially described them. It turns out that GDP/cap for Denmark in both current and fixed 1929 prices are a reasonable indicator for the EU subgroup (1b), in part because it dates back to 1818 and in part because the Danish economy was not so damaged by the two World Wars, see Figure 2.

Modeling the socio-technical evolution

According to Mensch's theory of technology development, the growth rhythms arise from accumulating of basic inventions (e.g. steam engine, cotton, railway, steel, electrical engineering, chemistry, automobiles or information technology) that launch technological revolutions leading to the creation of dominating communication, energy, transportation and production sectors for the certain period. The simple socio-technical succession model used for the wave forecasts is given below [6],

$$\frac{dU}{dt} = IP(F) - k_Q UQM(C)H(C/Q) \quad (1)$$

$$\frac{dQ}{dt} = k_Q UQM(C) + k_{IQ}C(Q - C) + \xi_1 \quad (2)$$

$$\frac{dC}{dt} = k_C C(Q - C)H(C/Q) + \xi_2. \quad (3)$$

where U, Q and C denote fundamental discoveries, innovations and capital, respectively. The parameter values k_Q, k_{IQ} and k_C for each wave are estimated based on the time series. $IP(F)$ is a Poisson process for novel discoveries, the
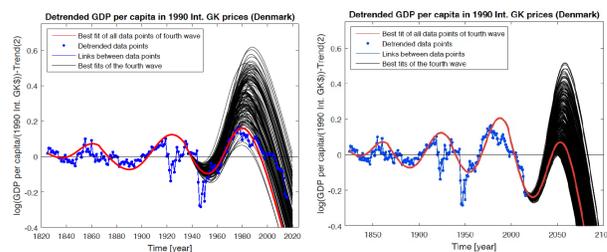
Figure 3: **Left panel:** Using the socio-technical succession model [6] we do Monte Carlo forecasting (assemble size 100) of the third Kondratieff waves based on previous GDP data and compare with actual data. **Right panel:** Monte Carlo forecasting the forth Kondratieff wave based on the previous GDP data.

functions H and M "opens" and "closes" the waves, while ξ_X denotes minute noice. For details, please see [6], [8] and [9]. Using Monte Carlo simulation of the model, we are able to forecast the expected fourth wave (see Figure 3). Obviously, forecasts of this type are not predictions. However, if the forth Kondratieff wave arrives, given the data and our assumptions, it should start around 2030. If not, we must conclude the Industrial epoch has concluded. Microscopic data investigations (not macroscopic GDP) may support answering this question in the near future, see e.g. [10].

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