ACCELERATING CHANGES IN OUR EPOCH AND THE ROLE OF TIME-HORIZONS

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Abstract: Technology shapes modern society at a scale unknown to our ancestors. During the last decades many observers noticed that improvements in technological capabilities seem to occur at an increasing rate. The emerging applications of nanoscience, biotechnology, information technology and cognitive science ("NBIC") are prominent examples - the NBIC-convergence an universally accepted fact. Progress especially in the field of life sciences, biophysics, and biology itself promise even more accelerated change/progress than the one shaped by IT so far. We show examples of these observations, discuss the modeling and simulation of those developments and discuss the effects in terms of technology and economics that prompt for more interdisciplinary research in this direction

Key words: Price dynamics; accelerated technological change; cobweb model.

1. INTRODUCTION

People living some 200 years ago found their century most exciting and promising. The inventions such as steam powered machinery and the subsequent economical, sociological and cultural change must have been overwhelming. The people thought about their predecessors as living in a medieval age. Since then new technologies arise more and more rapidly leaving us not only thinking about 1805B.C. as another medieval age but also now speculating about computation by means of single elementary particles[1], building space stations on mars[2] or evolving artificial life & conscience[3]. This feeling about a fast-pace progress can also be put into a more fact-based framework by inspecting several numbers. In the following we give some examples, describe one approach to quantify progress and finally introduce a model on our own from the field of econophysics.

1.1 Some First Observations

The rate by which new technologies are not only developed but also introduced/placed successfully in the marketplace is increasing. For example to reach 10 million customers in Germany manufacturers of communication technologies needed[4]: Telephone - 40 years, Fax - 20 years, Cell phone 10 years, Internet - 4 years. Other established technology based products are deconstructed and replaced in the market place at a rate unknown before[5]. But not only technology based products are in general on an accelerated scheme, also some other developments show the accelerated change in our epoch. Figure 1 shows for example the increased financial effort in education as the basis for further technological progress as a function of time in comparison to the Gross Domestic Product (GDP) in the US. While the rate at which the ratio grows is more or less linearly one has also to take into account that the US GDP has increased dramatically (nearly exponential) during that period thus boosting the expenses for education to new heights more or less every single year. While at the present it is unclear how educational levels translate into economic growth or technological change it is justified to assume a positive correlation between those observables.

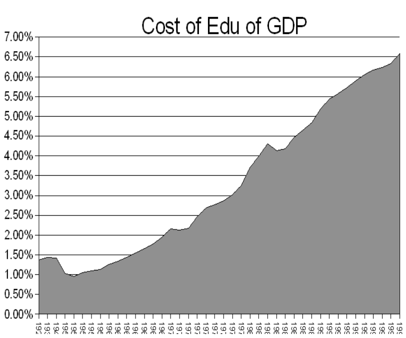

Figure 1. How much does the US spend on education with respect to its GDP? Note the (nearly exception less) monotonic increase and the fact that the GDP itself increases, too. [data from various .gov-sites]

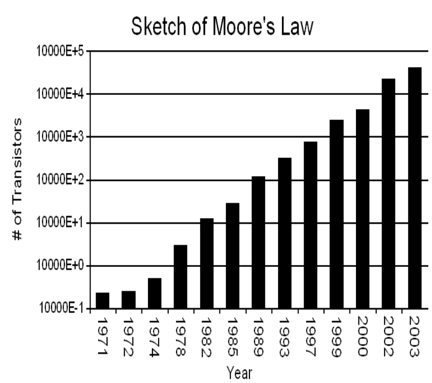

Figure 2. *Moore's Law [data from www.intel.com]*

Figure 2 shows the well-known Law of exponential increase in computational power/number of transistors on a CPU – named after the first business leader who mentioned it: Moore's Law. Although there are actually several versions of Moore's Law to take side effects into account and although it was argued that the strong exponential increase is not a strict as it was thought to be[6] we have to acknowledge a close-to-exponential increase in the computational performance anyway.

1.2 Implications and emerging questions

These findings prompt for some questions about the development to come.

- First of all we have to be sure about the observables that are reasonable, that provide answers for important questions. What exactly are suitable measures to indicate an accelerated change? Is it about economic figures? And most important: How to measure technology? Should we do so in more technical terms like computational capabilities or in economic terms such as utility of computation?

- If a satisfying measurement system is found, do we really observe acceleration in the change? Or does it manifest itself only in figures that are not important?

- If we accelerate any changes in our society, our technology - does this necessarily imply the existence of time horizons? What does happen beyond this horizon that indicates a phase transition (from the statistical physicists point of view)? Either we encounter a singularity (see below) in the advancement of civilization or there will be an upper bound to acceleration as the capacity of society and technical facilities reaches some saturation level. In the case of a singularity: Can we derive any knowledge when some technological Big Bang will occur?

2. MODELING (ACCELERATED) CHANGES

2.1 General remarks

In 1987 the Nobel price laureate in economics Robert Solow stated his concern[7] about an observation, which became known as the Solow Paradox: "You can see the computer age everywhere but in the productivity statistics."

Since then production theory tried to overcome this judgment with various approaches but it is still occupying a large fraction of researchers in this field to develop a suitable approach how to account for 'knowledge-related' productivity, wealth creation, value measurement and so on. For details see Triplett's discussion[8].

The quote itself is not necessarily meant to deny the productivity effects of IT but more a concern about the lack of a suitable measure. This is a most important issue as due to public awareness and media coverage the productivity numbers of national economies tend to influence policy makers all over the world – and the supra-national organizations such as the WTO or the IMF enforcing global trading policies. An accurate way to measure the influence of technology is therefore a prerequisite to use the results of productivity studies on the economic well doing and decisions that effect technological developments. In modeling we have always to keep in mind that direct comparison to empirical data is therefore complicated.

2.2 The Kurzweil Ansatz

Ray Kurzweil[9] introduced an approach to model accelerated change on a very coarse-grained scale – 'macroeconomics for technology' we would like to call it. He solely focused on computational power as a measure for progress – implicitly assuming that computation alone is feasible of bringing progress. Suppose there is a quantity V that somehow measures the computational speed available by the most advanced technology. Consider further the sum of all of our knowledge W. Both quantities are functions of time t.

Kurzweil assumes now that the speed of the best computational technology that can be built is proportional to the knowledge at a particular time: if you are capable of dealing with 'twice as much' technology you can built machines faster a factor of two in processing speed:

$$V(t) = c_1 W(t) \qquad (1)$$

2.2.1 Two models

Now his first model just states that the increase in knowledge is proportional to the computational effort we undertook in a time-period:

$$dW = V(t)\, dt \qquad \Rightarrow \qquad W(t) = c_2 \int_0^t dt'\, V(t') \qquad (2)$$

W is therefore assumed to be cumulative. Inserting Eq. (1) in Eq. (2) immediately brings us to $W(t) = \alpha_W \exp(\beta \cdot t)$ and from that

$V(t) = \alpha_V \exp(\beta \cdot t)$. So we obtain an exponential increase in computational power over time – which he relates then to Moore's law.

Model no. 2 tries to take the growing number *N* of resources capable of computation into account. But then the increase in knowledge is $dW = N(t) \cdot V(t)\, dt$. The computational resources *N* are also growing at an exponential rate $N(t) = \alpha_N \exp(\beta_N t)$ and again $V(t) = c_1 W(t)$. Then leads to $W(t) = \alpha_W \exp(\beta \cdot \exp(\gamma t))$ and therefore we obtain a very fast increase in computational capabilities $V(t) = \alpha_V \exp(\beta \cdot \exp(\gamma t))$.

These models come actually in several flavors. A published discussion actually shows that the authors tried to come up with a model that has actually a mathematical singularity[9]. But even without the mathematical form the increase is very fast. The term singularity is then used for the point of time when machines are able to sustain and improve themselves. From there on the acceleration is self-sustained as synergies across all technologies can be exploited. The predictability cease to exist at this point as we can make no assumption about what this 'new' world of machines will come up with – imposing a time horizon on our capability to make forecasts.

2.2.2 Some remarks on Kurzweil's Ansatz

Here we want to give a non-comprehensive list of criticism on the above-mentioned model:

- Coordination problem: Both model I and model II assume that the ratio between some measure of computational effort and knowledge is (nearly) linear. This is however a very optimistic assumption as the increase in the number of computational units makes it more likely that computations are repeated due to a lack of central coordination. If we however introduce some coordinating instance we face the problem that the growing number of processing units also leads to an exponential increase in the complexity of coordination – thus loosing most of the gained technological progress in bookkeeping.
- Moore's law: The ansatz itself relies heavily on the validity of Moore's Law. There are however different flavors (like number of transistors per square-inch, per dollar, per….). These gradual changes of the 'Law' over time was critically discussed by Tuomi[6] and might lead to the invalidity of at least model II.
- General sociological remarks:
    - The raise of a singularity can only occur if technology can improve itself without human interference. If humanity however does interfere due to social, ethical or philosophical (even selfish, e.g.

like Veenhoven[10] suggested) considerations than we have to rethink the model or even discard it.
  - Competition is not taken into account. While perfect competition can lead to an efficient market in comparison to a monopoly or an oligopoly the competition (between human beings, companies, countries) itself can waste resources that are assumed to work for a common goal in Kurzweil's ansatz.
- Resource allocation: While one variant of Moore's Law explicitly connects computational power and costs (that is Dollars) it is not clear how resources to design, built and maintain computational devices should be allocated. A market mechanism might lead to a very different response – if e.g. the marginal utility of computation is not perceived by (human) customers as valuable as the gain from some other investment.

2.3 Getting more detailed

We want not to be as bold as Kurzweil, but instead investigate the mechanisms at a more detailed level – in the analogy of above - a 'microeconomic approach' to modeling the accelerated change. This is however not a comprehensive description of all effects.

2.3.1 Appropriated measures

While it would be an intuitive approach to measure the impact of technology on our lives by values that are displaying some 'technological power' we do not follow this path here. First of all one has to admit that due to technological change the relevance of a certain number changes over time, in an accelerated world even more so. Take for example people some 500 years ago, their living was influenced by e.g. the speed of a horse or the speed of a boat but definitely not by the speed of computation. As a second argument for a non-technological measure of the impact of further technological progress one has to bear in mind that all technology has to be created from scarce resources. The allocation of those is however an economical process. From now we assume that a market economy will be the prevailing way to solve this distribution problem.

2.3.2 Economical modeling

We reduce our investigation on economical matters and thus broadening what has become popular as econophysics over the last years, see e.g. Feigenbaum's review[11]. Science as a production factor has become of increasing interest for economist[12]. Technological changes influence several aspects of the market:

- new products and services emerge
- production costs can be reduced
- prices can decrease due to the emerging competition or increase as a new technology might be perceived as more useful (more demand) and is protected e.g. by patents or comes in combination with another technology:
- substitution effects change the way goods are produced/consumed, e.g. a new technology replaces at least partially existing products thus decrease the demand for the substituted 'old' products
- positive correlation: one product might increase the demand for another, e.g. MP3-technology and CD-media to burn your MP3-library

We do not want to speculate on new technologies and the characteristics of those (see above for some thoughts about measures). We want however model and simulate the influence of abstract technologies on the economy. We are not concerned with problems of global trade (like taxes etc) and externalities (such as environmental pollution) here but assume just one global market place without any friction[1].

2.3.3 Classical price determination

One of the most well studied models is the cobweb-model. Here we assume market equilibrium at a particular time t (that is: everybody who wants to sell at a determined price sells, everyone who wants to buy at that price is able to buy → market clearing price). The market for just one good is described by a demand function and a supply function relating price to quantity of the good traded. This model already shows rich dynamics, even chaotic behavior[13,14,15,16] that was found to be present not only in the model but also in real-world data[17]. The onset of chaos manifests itself in positive Lyapunov-exponents of the time-series, implying a non-vanishing Kolmogorov-Entropy K. In the case of $K \neq 0$ we are confronted with a system that already has a finite time-horizon of predictability[18] as any predictions become inaccurate on a time scale $\propto K^{-1}$. The original cobweb-model explains just the price formation for one good. It doesn't account for product substitutions. The original studies focus on periodic, synchronous price determination (like seasons). Therefore the cobweb-model is most applicable for commodities like agricultural goods. These findings prompt for a careful modeling and analysis of accelerated change as time horizons might occur even in technological constant markets.

[1] These effects will be investigated in a forthcoming study.

2.3.4 Aspects of accelerated economics

Here we want to list some aspects that have to incorporated into a model for an 'economy' undergoing accelerated technological change.

Limited history Accelerated change means that all market participants – might they be consumers or producers – can only take limited information for granted. Prices, demands & supplies change also at an increasing schedule with improved technological capabilities. Price and demand/supply histories become less and less accurate.

Substitutions: Technologies are capable of replacing each other, like Email and fax machines, gopher and WWW services, or cars and trains. There is however a limited substitution capacity, e.g. without electronic signature you cannot transmit a legal binding document by Email while you might be able to do so by fax (depends on your government). If prices for technology A are higher than the amount we want to pay for it, we can substitute a competing technology B for it – at least a certain amount thereof.

Convergence and Synergies: Substitutions might even lead to phenomena called convergence nowadays. An example is the progressing integration of entertainment electronics into telecommunication devices (like games, cameras, MP3-player, radios etc). The progress in one area (like miniaturization) might help to improve another technology, too. If those synergies lead to a product providing every benefit of the former single technologies than we can replace those by that newly emerged one. The transition might however be characterized by a substitution behavior of buyers because the 'old' technologies might be cheaper and as well suited as the new one (see Substitutions above). A threshold exists below the maintenance of production units does not pay and a substituted technology gets discarded from the market (like telegraph services) completely.

2.3.5 Modeling such a market

At market clearing every item to be sold will find its buyer, so the price that is achievable is determined by the demand $d_t(p_t)$ where t is the time. The supply is determined as $s_t(p_t^e)$where p_t^e is the expected price at time t. At market equilibrium we have $d_t(p_t) = s_t(p_t^e)$. This already leads to a price dynamics, which is quiet rich as can be seen in figure 3.

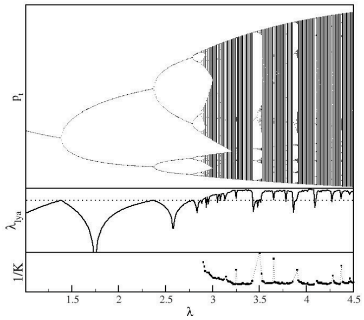

Figure 3. Rich Dynamics of prices, their Lyapunov-exponents and the resulting Kolmogorov-Entropy. A nonvanishing entropy implies a time horizon for the price predictability

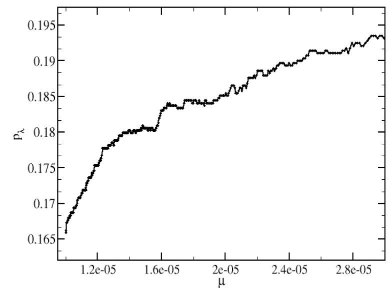

Figure 4. Probability to encounter a time horizon in the price dynamics with respect to rate of technological change.

The details of the model and the subsequent analysis can found elsewhere[19]. If now introduce a rate of change μ to mimic substitution as well as decrease in the relevance of historical knowledge about the market, we can observe various effects that most of all lead an increase in the non-trivial behavior.

Figure 4 shows the result for a particular parameter set. The dynamics gets richer the more change is facilitated in the production of goods. We thus conclude that the accelerated change of technological production capabilities induces more chaotic price dynamics, thus more often time horizons.

3. SUMMARY & CONCLUSIONS

In this contribution we described some developments that modern society faces. Technological advances pose a challenge for existing technologies, the economy and the society. We showed three indications of an acceleration of change and discussed possible impacts and accompanying questions. We mentioned the ongoing controversy about suitable measures and described one coarse-grained model that produces a technological singularity (Kurzweil). We continued with some remarks on the limited applicability of this model and introduced a more detailed model in the spirit of econophysics (cobweb and the extension presented here). We described some of the findings that are characteristic for this model and put the results into the context of real-world developments. We hope to have encouraged further interdisciplinary research, which in our point of view is the only feasible approach to grasp future development in society and the economy.

REFERENCES

1. J. Stolze and D. Suter, *Quantum Computing: A Short Course from Theory to Experiment* (John Wiley & Sons, New York, 2004).
2. NASA, http://weboflife.nasa.gov/currentResearch/currentResearchGeneralArchives/ inspiration.htm
3. C. Gros, Autonomous dynamics in a dense associative network for thought processes, 2005,(submitted)
4. R. Bargsten et al., Digitale Trends, Erwartungen, Realität und Perspektiven, 2004,Wirtschaftsrat der CDU e.V. Landesverband Hamburg
5. P. Evans, T.S. Wurster, *Web Att@ck*, (Hanser Verlag, Hamburg, 2000).
6. Ilkka Tuomi, FirstMonday **7**,11 (2002).
7. R. Solow, New York Review of Books, 1987
8. J. Triplett, Canadian Journal of Economics **32**, 309-334 (1990).
9. http://www.kurzweilai.net
10. R. Veenhoven, Social Indicators Research **20**, 333-354 (1998).
11. J. Feigenbaum, Rep. Prog. Phys. **66,** 1611-1649 (2003).
12. Paula E. Stephan, Journal of Economic Literature **34**, 1199-1235 (1996).
13. R.V. Jensen, R. Urban, Economics Letters **15**, 235-240 (1984).
14. Z. Artstein, Economics Letters **11**, 15-17 (1983).
15. A. Matsumoto, Discrete Dynamics in Nature and Society **1**, 135-146 (1997)
16. C. Chiarella, Economic Modelling **5**, 377-384 (1988).
17. A.J. Lichtenberg, A. Ujihara, Journal of Economic Dynamics and Control **13**, 225-246 (1989). 18. H.G. Schuster, *Deterministisches Chaos* (VCH, Weinheim, 1994).
19. Kay Hamacher, Impact of accelerated technological change on price dynamics, 2005 (submitted).

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NOTES

 For details on this and future work please visit the author's website http://ww.kay-hamacher.de