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Contents

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Preface

New developments in bio- and nanotechnologies and also in information and communication technologies have shaped the research environment in the last decade. Highly educated experts in R&D departments work together with scientists and researchers at universities and research institutes for creating new technologies. Transnational companies which have acquired various firms in different countries deal with the management of their diverse R&D strategies and cultures. Different disciplines have to be brought together in developing new technologies. Researchers and educators increasingly collaborate across borders throughout the globe. The knowledge-based economy permeates across companies, universities, research institutes, and countries. Managing technology in this new environment presents real challenges.

Some aspects of these challenges have been reflected in varied contributions to the 14th International Conference on Management of Technology convened during the period of May 22-26, 2005 in Vienna, Austria. The conference subtitled "Productivity Enhancement for Social Advance: The Role of Management of Technology" was hosted by United Nations Industrial Development Organization (UNIDO) and organized by Mohamed El-Nawawi and Marianne Hörlesberger in Vienna together with Tarek Khalil and his team in Miami.

Remarkable contributions came from researchers working for UNIDO in its different offices around the world. They focused more on the industrial and technology developments in developing countries. When we started working on this book, UNIDO requested to publish a specific book dealing with these aspects. Hence, the emphasis of this book is on the general contributions to the conference in other challenging technology management issues.

The book is organized in six sections, with papers in each section revolving around specific themes: managing new technologies; business organisation; technology and innovation management; standards and evaluation methods; sustainability; and social and educational aspects in MOT.

IAMOT expresses its appreciation to the many organisations, companies and the government in Austria that supported the 2005 IAMOT conference, especially UNIDO; the Federal Ministry of Transport, Innovation and Technology; the Federal Ministry of Economics and Labour of the Republic of Austria; and the Federal Ministry for Education, Science and Culture.

The editors would also like to express their appreciation for the individual contributors to this volume.

Marianne Hörlesberger and Tarek Khalil
Austria Research Centers GmbH - ARC, Vienna, Austria
and University of Miami, Florida, USA

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CHAPTER 32

COMPLEXITY, COST REDUCTION AND PRODUCTIVITY IMPROVEMENT THROUGH HISTORY

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History shows us that in the cost/performance ratio of any given product has decreased continuously. This may wrongly have led us to the conclusion that improvements can continue infinitely at the current pace. Our proposition is that we trust a mental picture that is not consistent with the future level of potential improvements in technology and business, which in turn has repercussions for societal change.

1. Introduction

Anthropologists and historians have increasingly turned to economic explanations behind basic social inventions in human history, such as the transition from hunter-gatherer societies to agriculture, including the domestication of animals and plants. Diamond (1997) argues that agricultural societies created specialised roles in society. The increased productivity in agriculture compared to hunting and gathering made it possible to set aside resources to maintain chiefs and later a growing number of court people, administrators and other officials. Thomas (1982) describes how the invention of better and better ploughs made it possible to plough deeper in the ground, which made the soil more fertile. The result became bigger crops. With agriculture came the domestication of plants, which meant that the cobs of corn became larger (the wild ancestor of corn had cobs that were smaller than a thumbnail)

(Diamond, 1997). This article puts the more recent development in agriculture and business into this historical context.

The industrial revolution, gene technology, biotechnology and other important technological developments are based on the same basic logic as the development of early agriculture. One of the main benefits of these developments is the improvement of productivity in various ways. The cost/performace ratio for a comparable product has continuously been reduced. This has been shown for various products such as crushed and broken limestone as well as integrated circuits and RAM components (Ghemawat, 1985; Hill, 1985). The commonly held perception is that productivity can improve infinitely. Tainter (1988) argues that economic development causes increasing specialisation and, consequently, an increase in complexity in society. He also argues that increasing complexity has been the cause of the collapse of complex societies through history.

We use a theoretical argument taken from agriculture and empirical data from the printing industry in our analysis in order to argue that economic development reduces unit production cost in the direction of zero, but that recent technology developments may reduce, rather than increase, complexity.

2. Proposition

We propose that the picture of unlimited economic growth is not a correct mental picture for productivity improvements. We rather suggest an X-Y diagram with cost and time on the axes indicating the absolute level of cost and time possible is zero cost and zero time hence a finite potential for productivity improvements and economic growth. We also propose that this will have negative implications for the continued development of our society.

3. Theoretical Foundation

Porter (1996) argues that the development of productivity is a trajectory of productivity improvement “outward” with no end to the potential improvement.

Instead we argue that development is clearly moving toward the limit of cost improvement. No product can be produced at a cost that is lower than zero units of input per unit of output. The closer to zero this development moves, the lower the value of a further improvement. This means that in the days when humans were hunters and collectors, the value of being able to set aside one person in the tribe to tend full time to improving society was very high. The archaeologist Tainter (1988) puts this as the ability of a tribe to increase complexity by starting on the path of specialisation, and argues that this increase in complexity brought comparatively large returns to the tribe. Gradually, as the development of agriculture and social complexity in general has developed, the returns to an investment in further complexity decrease and eventually become negative. In a situation today where one farmer is able to produce food for a large number of people, each improvement brings smaller returns. The value of a further investment in complexity (specialisation) becomes smaller and smaller the more complex society grows. Tainter defines complexity as the degree of specialisation in a society. Specialisation is measured as the number of specialised jobs that exist in a society and the number of specialised tools that people use in order to perform various tasks. In the least complex societies there is virtually no specialisation. Tainter mentions the Ik of Africa, as the least complex of all known societies, where everybody cares only for himself. In our society we have several thousand different jobs and tens of thousands of different tools that we use for different purposes (Tainter 1988) and each person is highly dependent on the fact that others perform their jobs in order for society as a whole to function.

Specialisation in society has been highly augmented since the industrial revolution. At this time the industrial production of farming equipment started, the food processing industry and large-scale food distribution into the growing cities grew as well. Farming, food production and distribution had formerly been integrated in the production on farms and were from the industrial revolution and onwards increasingly broken down into more and more specialised businesses, each using more and more efficient organisational models, equipment and marketing tools in order to compete. The specialised functions of suppliers of raw materials machinery and maintenance, agricultural production, refining, wholesale and retail developed. These developments contributed to increased productivity up to the present level where 3 per cent of the total population that is employed in farming in the industrialised world can produce the agricultural raw materials that feed the whole population and also produces a surplus in the developed countries. In total, a larger share of the population is involved in the whole chain of food production and distribution, but the total number has decreased compared to the levels before the industrial revolution.

According to Tainter, complexity could only profitably be increased up to a certain level. In an advanced society, such as the ancient Egypt, the Maya empire and our society, the value of a further increase often becomes negative. The cost of maintaining complexity increases to a level where complexity becomes costly to sustain and society becomes vulnerable to disruptive events that could previously be successfully handled when the level of complexity was lower. The reason for this vulnerability is that a substantial share of the resources in society is used in order to maintain the status quo. If, through some type of shock or crisis, problems appear in any of the supply chains for resources, the society is hurt and run the risk of declining. In early agricultural societies this type of shock may be caused by a prolonged draught or invasion by other clans or nations. In a modern society it can be caused by political upheaval (Tuchman 1984) in a resource rich country or by increased scarcity in oil or other fossil fuels (Heinberg 2003). Tainter (1988) argues that the Mayas and the Romans were able to handle shocks in their growth phases when the returns to increasing complexity were still substantial, that they were less able to handle towards the end of their empires when the returns to increasing complexity were low. Heinberg (2003) argues that the use of fossil fuels has given humanity a brief period with access to cheap extra energy. Each person uses the equivalent of the energy of some fifty slaves that we are able to pay for mainly through the low cost of fossil fuels. We are now approaching the maximum point of oil extraction. The cost of finding new oil resources and exploiting them is now several times higher than they were in 1960. The ability to maintain industrial society based on access to low cost energy will not last. Oil and other existing energy sources will become increasingly scarce and expensive. New sources of energy are not developed rapidly enough in order for production from these sources to grow at the rate that fossil fuels are depleted. Thus, we must expect the cost of energy during the next few decades to increase sharply and our ability to maintain a high level of complexity may thus be reduced (Heinberg 2003).

Larsson (2004) argues that there are definite limits to the reduction of time and cost. Nothing can be done in less than no time and at less than no cost. In many areas companies are coming closer and closer to this limit. This is true especially for information flows, where any piece of information, such as a book or a film can be electronically copied and distributed to any place in the world in close to no time and at close to no cost at all. In the case of material flows we will not be able to produce or distribute physical products at zero cost, but we are gradually coming closer to this limit by systematically reducing the non-value added time and cost in production processes in the direction of zero. Efforts in business, such as Buiness Process Reengineering, Supply Chain Management and the digitalisation of production and administrative processes and work flows inevitably lead to the reduction of time and cost towards zero. This has not previously been noticed by researchers (Larsson 2004).

4. Empirical Evidence

We have applied the theory of increasing complexity to the printing industry in order to study the increasing complexity of printing in terms of increasing specialisation. Our findings are not conclusive, since the development of printing is no longer confined to the printing industry itself, or to the printing industry and the printing machinery industry.

4.1. *Copying by scribes*

Prior to Gutenberg's invention of movable type in the western hemisphere, most duplication of written matter was done by scribes who were employed in the courts of wealthy people (Eisenstein 1983). At this time four or five persons were involved in the transaction of writing, copying and purchasing a book. In case more than one scribe was involved, this does not increase complexity in the sense of Tainter (1988). The persons involved were the author, the scribe, a binder and the buyer. Sometimes, a middleman, such as a book wholesaler (Eisenstein 1983) was also involved.

4.2. *Printing with movable type*

Through the invention of the printing press and movable type, we are able to identify a number of specialised tasks that was significantly larger than the above figure. We identify the following seven tasks:

- writing
- casting of type (Gutenberg devised the original formula for mixing tin, antimony and lead to the material that is still used, nearly unchanged (Adams & Dolin 2002).
- typesetting
- printing
- storing already printed pages
- sorting and assembling a book
- binding

In addition to this a further new role was introduced in the industry, the machine constructor and, the maintenance person. The supply chain, which initially consisted of the suppliers of paper, ink and carpentry (who supplied the table for writing on), was extended by the smith.

Through the mass production of books and other printed matter a system of distribution was gradually developed, which involved:

- sales from the print shop
- wholesalsers
- retailers

Through the “printing revolution” of Gutenberg, it was possible for his team to print and bind 200 copies of the Bible in only three years (Adams & Dolin 2002).

4.3. *Offset printing*

Through the development of later generations of printing technology each of the above specialised tasks has been developed into further specialisation. In a printing company we may have five departments:

- sales
- pre-press
- printing
- post-press
- administration

In each department there are several specialised tasks. In the pre-press area, the material is prepared for printing, formats are chosen and contrasts and colours are set. At the end of pre-press printing plates are made. Similarly, there are a number of tasks in the other departments.

Even if a printing company today may only contain 30 persons or less, this company relies on a large number of suppliers for its efficiency and for the improvement of its productivity. Suppliers of software and hardware supply the computers and the machinery in each department, such as cameras, densitometers, film-processing units and screens in pre-press. Colour printers and black/white printing machines are complemented by computerized control equipment in the printing area and in the post-press area companies have sorting machinery, saddle stitchers and book-binding equioment.

In each department a number of consumables are used. The most obvious would be printing plates, paper and inks, but there will be plastic folios, adhesive tape, glue, cloth and a number of other types of consumables that are used. These consumables are supplied by companies specialised in different areas, such as ink companies and paper companies. Some of the more important suppliers of a modern printing company would be Microsoft, Adobe and IBM. In addition to these companies there would be suppliers of pneumatic valves, rollers for the print engines and other machine parts for printing presses and other equipment that may be purchased via the machine supplier or directly from the subsystems supplier.

Today it takes a few hours to produce 200 bibles. For a very small run, such as 200 copies, the cost of setting up the press and print the make-ready may cost as much as the printing of the actual production run (Adams & Dolin 2002).

4.4. *Digital printing*

"Digital printing has revolutionized the printing industry. It has changed the production cycle and drastically shortened the turnaround time of a job." (Adams & Dolin 2000)

Digital printing again changes the complexity of the printing industry and this time it seems as if it <u>reduces</u> the complexity of the printing process, by compounding a number of tasks in the printing company into the main activity of printing, sometimes with integrated post-press.

A digital printing machine prints all pages in a sequence, similar to an office printer. There is no need for printing plates, storage of already printed pages or sorting in the process of assembling the book or magazine. Instead, a digital printing company may still consist of the same departments as in the offset printing industry, but the work in the printing department may have been "revolutionized", because a number of manual tasks have been taken away. The post-press activities can be organized in-line with the printing, so that the printing and post-press is seamlessly integrated. This gives rise to the term "print-on-demand", because printing of single or a few copies of a book or a magazine becomes possible. Adams & Dolin (2002) not only foresee changes in the printing industry through this development, they foretell the elimination of traditional bookstores.

Through the simplification of the printing process, the printing machinery is also simplified with fewer subsystems and fewer specialized technologies. This development may indicate that there is not necessarily a direct relationship between increased complexity and cost reduction, as has been the case earlier in history (Tainter 1988). In the case of digital printing this technology seems to reduce the complexity in terms of the specialization of tasks. Yet, it decreases the cost of printing. According to our studies, it initially reduces the cost of small runs, up to

100 copies, so that a large publisher of literature for higher education in Sweden produces all runs shorter than 100 copies in a digital press. Adams & Dolin (2002) argue that digital production of colour copies can be done for close to 50 cents a page, which may make the market demand for colour documents to take off. Gradually, the cost of printing each copy, irrespective of the size of print run is being reduced in the direction of zero, through the development of the machinery towards increasingly efficient machines with increasing speed and capacity.

Through the most modern and largest of Xerox digital presses, iGen, (Xerox is the market leader in the market for digital printing equipment), digital printing is competitive against offset printing for increasingly large runs. Runs of 250 or more copies may be comparable to the offset price on a direct price comparison basis. If the cost of storage and waste on offset print runs is included, an offset run of several thousand may be broken down into a number of shorter runs, which offers a number of added values for digital printing, described by Larsson (2004).

The amount of manual labour that is needed in digital printing is very low, compared to offset printing and the only manual tasks in the printing and post-press stages in an on-line post-press situation, is the feeding of paper and the emtying of the tray of finished product. The cost reduction in the digital print industry is expected to continue so that increasingly large runs will be taken over by digital printing (Adams & Dolin 2002).

This study of the printing industry indicates that cost reduction through history has brought the per unit cost of printing increasingly close to zero. The cost is not yet zero and there is further room for cost reduction, even though a substantial share of manual tasks have been taken away since the time of Gutenberg and some more are taken away through the current transition to digital printing. The machine time that remains can be further reduced through increases in speed. However, contrary to the argument of Tainter (1988) as indicated by the case study of digital printing technology and specialisation, cost reduction may not always be dependent on an increase in complexity, even if this has been the case up until very recently, at least in many industries.

5. Conclusion

Only a very small share of technology development propels the economy into entirely novel areas (Larsson 2004). As we are approaching zero cost and time in current processes such as technical operations, commercial operations, financial operations, security operations, accountancy operations and administrative operations, as the key processes in companies were named already in the first decade of the twentieth century by the French organisation theorist Henri Fayol (Sanchez & Heene 1997), we have to expect that the growth in these processes that has historically been caused by cost reduction will decrease as well.

Tainter (1988) forwards the hypothesis that the fall of complex societies through history has been caused by the increasing complexity and the diminishing returns to investing in more complexity at later stages. He uses the example of the cost of maintaining order in the Roman Empire at the cost of maintaining large legions, which had to be paid for through taxes. Tainter also uses the modern example of oil production to illustrate his argument, a theme further developed by Heinberg (2003).

Our study of the printing industry, however inconclusive, indicates that cost reduction may not always be accompanied by increasing complexity. However, in the case of digital printing, the path towards a further reduction in per unit cost seems to be maintained and this, according to Larsson (2004) creates a possible risk of economic collapse for our present society.

With an economy that in many areas is coming closer to the limits of business development and economic growth, by coming closer and closer to zero cost, the value of a further increase in complexity will be reduced further. In many instances of information flow within companies and between companies and public organisations, the cost of creating and distributing information is very close to zero. Ten years ago such flows often involved large numbers of people in a number of different organisations. Today, completely automated and computerised transactions are transmitted inside companies and between companies at the cost of a few cents per transaction (Larsson 2004). In such cases and in many material flows as well, where most of the non-value added cost has been taken away in process improvement projects during the last decades, the value of a further improvement, by definition, becomes smaller and smaller. In the case of material flows in production and distribution the cost of material flows is not coming close to zero, because of the obvious need for resources to produce and distribute material goods. In these cases, development has been focused over the centuries on the reduction of non-value-added cost and this cost has been reduced to very close to zero during the past few decades in particular (Larsson 2004). This has been done through the development of new materials, production technologies and distribution systems, together with management principles that support radical cost reduction in area upon area.

In this sense, as argued for the case of agriculture and printing above, the present may bring us close to the end point of thousands of years of human development at least from the aspect of cost reduction and productivity improvement. Nothing can be done at less than no cost and when we have taken away almost all cost in a number of specialised information flows and almost all non-value added cost in many advanced material flows, we can't continue further on this trajectory. Printing is only used as an example.

Economic growth is based on improvements in productivity (De Long 1991). If the historical improvement in productivity is moving towards an absolute limit in further improvement, since nothing can be done in less than no time or at a cost that is lower than zero, the limit to productivity improvement may prove to be a more difficult obstacle for our society in the near future, than the diminishing returns to increased complexity, as is argued by Tainter (1988).

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Author Index