The knowledge economy in historical perspective

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Abstract

The knowledge economy has been seen as providing huge opportunities for economic growth and to become the cornerstone of future economic development. Still, what are the historical roots of the knowledge economy, and how has it evolved in the long run? To answer these questions, this paper puts the knowledge economy into a broader historical context. We present various concepts of the (very) long-run evolution of different components of the knowledge economy. The paper combines this overview with the broad economic changes which are related to the growth of knowledge and economic prosperity in the longer run.

Keywords: Knowledge Economy, Education, ICT, Economic Growth, Digital Economy

JEL Codes: N33, I28, O31

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1. Introduction

The knowledge economy has been hailed to bring about a new era of economic prosperity and fundamental changes to the way the future economy might work. Knowledge is considered to be at the heart of the future economy. However, the relevance of knowledge for innovation and economic growth is nothing new. It has been singled out by a large literature, beginning with Adam Smith (see Demeulemeester and Diebolt 2011). After major contributions by Becker (1964) and Schultz (1961) in the human capital literature, a new wave of research followed the creation of the endogenous growth models (e.g. Romer 1986, Lucas 1988). Therefore, human capital and knowledge have been established as important factors for growth. Still, the generation of knowledge has only recently achieved new heights thanks to new information and communication technologies, in particular the internet. The internet and the digital economy have been transforming the economy as a whole. However, one may expect much more to follow, as the internet is arguably still in a relative early phase. Yet the internet may not only provide new business opportunities but also alter the way we learn and educate ourselves. The traditional schooling model is increasingly challenged by more flexible alternatives that include the efficient use of online materials and courses.

While the future direction of the knowledge economy is uncertain, it is crucial to see the more recent events and transformations in a larger picture. This larger picture may allow us to have an idea of what the knowledge economy really is and how it has come into being. This may give researchers and policy makers a broader understanding of recent trends and provide some inspirations in what directions future research and policy directions should be directed.

For this reason, this paper considers some concepts of the (very) long-run evolution of different components of the knowledge economy. In particular, we consider

the broad changes in the area of education and the fundamental transitions in knowledge production. The latter have particularly been influenced by the invention of new information and communication technologies such as the printing press and the internet. The paper combines this overview with the broad economic changes that they have brought about and the growth of knowledge and economic prosperity in the longer run.

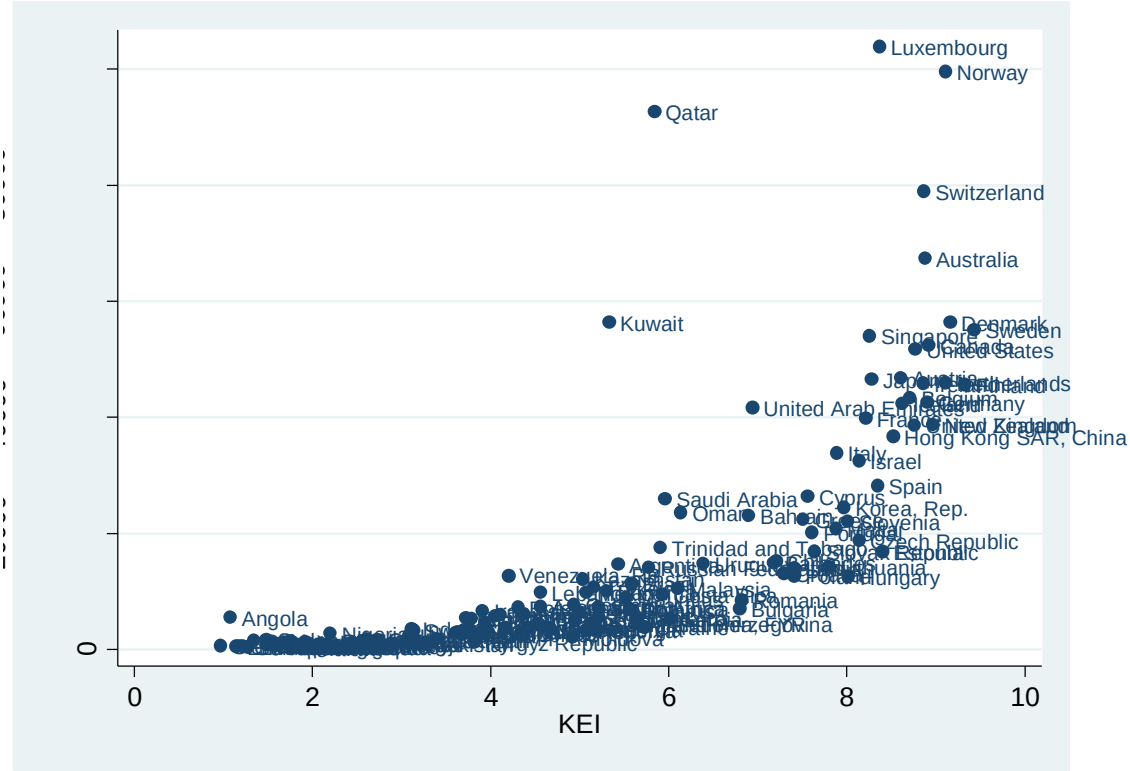
The paper is structured as follows. First, we introduce the basic theoretical concepts of the knowledge economy, human capital, skills and knowledge. Then, we present the three eras of education, before continuing with the four stages of long-run knowledge production. Subsequently, we show the potential economic implications of these transitions. Finally, we consider the growth of information and knowledge and economic prosperity. A conclusion sums up the paper.

2. The knowledge economy, human capital, skills and knowledge

First of all, we need to specify some of the most important terms that are often used in the context of the knowledge economy. Surely, one has to start with the term 'knowledge economy' itself. There are many possible definitions. Within the framework of this paper, we may use the concept of the World Bank. The World Bank has constructed the 'Knowledge Economy Index' (KEI). This index is significantly correlated with GDP per capita (Figure 1). The KEI comprises various indicators of four pillars that make up the knowledge economy. These pillars are the economic and institutional regime, education and skills, information and communication infrastructure and the innovation system (World Bank Institute 2008).[3]

[3] More specifically, these indicators are tariff and non-tariff barriers, regulatory quality and rule of law (economic and institutional regime), adult literacy rate, gross secondary enrolment rate and gross tertiary enrolment rate (education and skills), telephones per 1,000 people, computers per 1,000 people and internet

Figure 1 KEI and GDP per capita, 2012



Source: Own presentation, data by World Bank (2014a, b).

Therefore, the KEI is more broadly defined as what has been the focus of this paper, namely education, knowledge and information. Our focus corresponds roughly to pillars 2 and 3. Although, according to the World Bank, the knowledge economy includes some further important pillars and dimensions, the KEI does emphasise the relevance of the topics considered in this paper.

The next question we need to consider is the definition of human capital. According to Nobel laureate Gary S. Becker, human capital can be defined as "the knowledge, information, ideas, skills, and health of individuals" (Becker 2002, p. 3). More

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users per 1,000 people (information and communication infrastructure) and royalty payments and receipts in US$ per person, technical journal articles per million people, patents granted to nationals by the U.S. Patent and Trademark Office per million people (innovation system) (World Bank Institute 2008, p. 3).

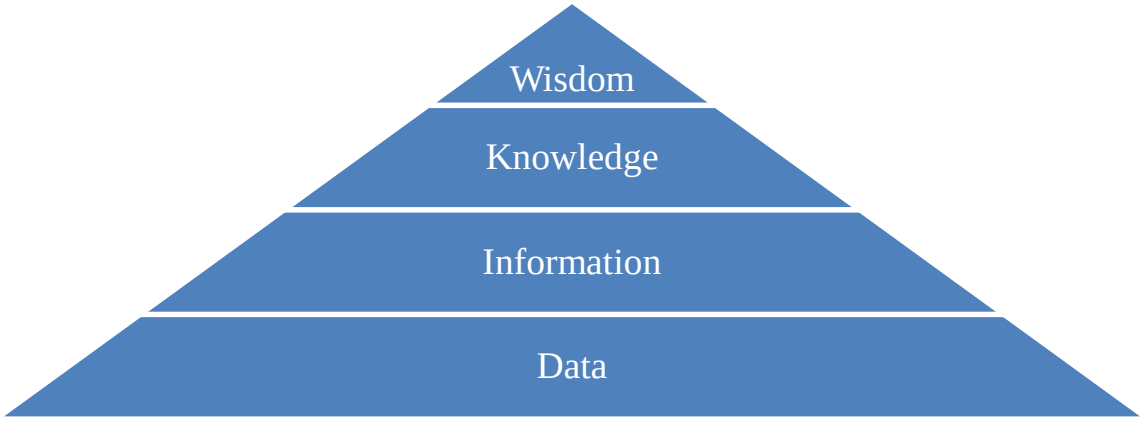
precisely, Nobel laureate Theodore W. Schultz notes that human capital "is a form of capital because it is the source of future earnings, or of future satisfactions, or of both of them. It is human because it is an integral part of man" (Schultz 1972, p. 5). In addition, "[t]he most critical attribute of human capital arises from the fact that the person and his human capital are inseparable. The person must always be present wherever the services of his human capital are being rendered" (Schultz 1972, p. 8). These definitions clarify the notion of human capital and that skills and knowledge are parts of human capital.

But what are these 'skills', to which Becker refers? According to the OECD, skills can be defined as the "abilities and capacities people have to perform tasks that are in demand in the workforce […] [which] are usually acquired through education, training and/or experience" (Martinez-Fernandez et al 2010, p. 31). More specifically, one can distinguish between three categories of skills: "[b]asic skills are those more generic and routine skills that can be found in occupations present in most industries and organisations. Advanced skills have a higher component of knowledge intensity and can be found in technical occupations and management positions but also refer to social and communication skills needed for team work and specific language and cultural skills that are of growing importance in certain multicultural working environments. Converging skills require several of the other skills plus some specific skills" (Martinez-Fernandez et al 2010, p. 31).

Next, it appears important to get some more intuition on what is meant by the terms knowledge and its relationship to data and information. In many cases, these terms are erroneously used as synonyms. For example, terms such as the 'knowledge economy' or 'information economy' often imply the same. The difficulty is that there is not yet a clear and largely accepted definition for each term. For example, Zins (2007) presents 45 different definitions proposed by the specialised research community. For this reason, we

limit ourselves to a representation which is (at least) "one of the fundamental, widely recognized and 'taken-for-granted' models in the information and knowledge literatures" (Rowley 2007, p. 163-164).[4] This representation is the knowledge pyramid, more clearly called the data-information-knowledge-wisdom hierarchy (DIKW).

Figure 2 The knowledge pyramid



Source: Based on Ackoff (1989).

Ackoff (1989) has been widely cited in this context. He proposes the following definitions and shows how one element is transformed to the next higher element. First, data can be defined as symbols representing the properties of specific objects, events and their respective environment. They can be observed, yet they have to be brought to a usable form. In consequence, it is not a structural difference that distinguishes data and information but a functional one. Second, descriptions contain information. They answer questions such as 'who', 'what', 'when' or 'how many'. Information systems are more complex and are responsible for the generation, storage, retrieval and processing of data. Information can be obtained from data. Third, knowledge can be described as know-how. In other words, knowledge enables to transform information into particular instructions.

[4] See also Rowley (2007) for a critical discussion of this model.

There are three ways that knowledge can be received: from another person, from experience, and from instruction. Finally, wisdom is the last and highest category of the pyramid. It enables to generate a higher level of effectiveness. It brings about value-added by the use of judgement. This judgement involves certain values in the ethical and aesthetic dimension which are unique and personal to the actor.

It goes beyond the intention and the framework of this paper to discuss these definitions in more detail. Still, they give a clearer idea of what human capital is and what knowledge is. They emphasise that human capital and knowledge are inherently intertwined.[5]

In sum, the importance of human capital as a productive resource cannot be underestimated, as has been neatly put forward by Schumacher: "[a]ll history – as well as all current experience – points to the fact that it is man, not nature, who provides the primary resource: that the key factor of all economic development comes out of the mind of man. Suddenly, there is an outburst of daring, initiative, invention, constructive activity, not in one field alone, but in many fields all at once. No-one may be able to say where it came from in the first place; but we can see how it maintains and even strengthens itself: through various kinds of schools, in other words, through education. In a very real sense, therefore, we can say that education is the most vital of all resources" (Schumacher 1974, p. 60).

[5] More generally, note that human capital is arguably not only a crucial factor for economic growth but also for the self-definition of humans. Remember that our species is called 'homo sapiens' which can be translated as 'wise man' (after the classification of Linnaeus in 1758). Species are normally defined by some physical trait, but what may make humans different from animals are not their physical characteristics but wisdom, or in other words human capital.

3. The three stages of education

If education is the most important of all available resources, including natural resources, we need a broad understanding of its overall evolution, particularly to better grasp the implications of improvements in education in a future knowledge economy. To simplify this evolution, we may think of different stages in education. The intertwined relationship between education and economic development is evident because a major watershed in education took also place during an economic revolution, i.e. with the Industrial Revolution.

In particular, Collins and Halverson (CH, 2010) divide human history into three educational stages or, in other words, two educational revolutions. They suggest that we are at the brink of a new, second educational revolution which may transform the way we learn and think about education. They compare three different stages or 'eras' of education in history: the apprenticeship era, the universal schooling era and the (future) life-long learning era. Clearly, CH simplify historical processes to a huge extent. Still, their simplifications might allow some general insights. Thus, the apprenticeship era is argued to have lasted roughly until the Industrial Revolution.[6] Universal schooling was introduced in more and more countries during the Industrial Revolution. We are now beginning to enter the third era, the life-long learning phase. However, this second educational revolution is still to unfold, so that CH's ideas are still visionary and futuristic (and certainly open to debate).

[6] Although it appears clear that universal schooling began with an important time lag after the Industrial Revolution in a number of countries, including the UK. In other countries, such as in the developing world, universal schooling took place much later. Therefore, the reference to the Industrial Revolution can only be taken as a very crude measure. Similarly, schools already existed during the apprenticeship era and apprentices still exist today. However, one may use CH's ideas as a general tendency in the history of education.

The importance of technologies is crucial in both educational revolutions. CH argue that the development of the universal schooling system was driven by the introduction of novel information technologies, including textbooks, the widespread use of bureaucratic information systems and new ways of assessing students. Similarly, new information technologies such as computers and the internet may have the potential to fundamentally change the way people acquire skills and learn. At least a part of the 'old' school system and the way children are educated may become obsolete and redundant. These systems would need a new restructuration, including new learning environments.

More specifically, the three eras of education differ in a number of crucial dimensions (see Table 1).

Table 1 Comparison of the three eras of education

Dimension	Apprenticeship	Universal schooling	Life-long learning
Responsibility	Parents	State	Individual, parents
Content	Practical skills	Basic skills, disciplinary knowledge	Generic skills, learning to learn
Pedagogy	Apprenticeship	Didacticism	Interaction
Assessment	Observation	Testing	Embedded
Location	Home	School	Multiple
Culture	Adult	Peer	Mixed-age
Relationships	Personal	Authority	Computer-mediated

Source: based on Collins and Halverson (2010).

First, universal schooling was synonymous with a major increase in responsibility and power of the state over children. Before universal schooling, parents were predominantly responsible for their children and thus also for their education. Later on, the state took over their place due to a variety of reasons (e.g., public control, language harmonisation, nation building, etc.). CH suggest that in the future, the role of the state will be once again smaller, and the main responsibility will shift to parents of small children and individual learners at older ages.

Second, according to the OECD, "skills have become the global currency of the 21st century" (OECD 2012, p. 3). But what kind of skills are essential? Skills have always been important, but the type of skills and thus the content of education has changed. Whereas practical skills were most important during the apprenticeship era, universal schooling put more emphasis on basic skills such as basic numeracy and literacy. Knowledge was provided according to different relevant disciplines. What might be crucial in the new era are more generic skills (e.g., problem solving) and the ability to know where to find information and how to learn from these resources.

Third, the pedagogical foundations of education were formerly based on observing, teaching and practising in the apprenticeship era. Young adults learned particularly by watching a master, memorising and repeating his steps. The more a young adult has learnt, the less the master needs to help him. This focus turned to the direct lecturing of children with the help of textbooks and written tests. In the future, interaction might be fundamental, in particular with computers and other learners through networks.

Fourth, masters watched their apprentices performing their tasks and, when necessary, corrected them. At school, tests were developed that aimed at evaluating the performances and skills of students in this way. In many cases, only if students pass these exams they are allowed to move to the next higher level. In the third era of education, assessments will possibly be much more based on different levels that have to be achieved in computer-learning software. Due to this step-by-step and task-related approach, in this dimension it might resemble more the apprenticeship than the universal schooling era.

Fifth, apprentices normally obtained their skills in their parents' home as well as the home and workshop of their master. The location of education clearly shifted to the school after the Industrial Revolution. Schooling was supposed to prepare them for their later industrial life. The future will possibly see a much more customised way of educating

children because the internet allows to learn anywhere. Therefore, education will not only take place at school but also at home, in workplaces and specifically designed learning centres.[7]

Sixth, children normally learnt from adults during the apprenticeship era. Of course, teachers were also essential for knowledge transmission in the universal schooling era. But many cultural aspects were acquired through the interaction with peers in the same class, with both positive and negative effects. In many circumstances, the negative influence of peers was detrimental to learning. In the life-long learning era, learning will take place more with a variety of individuals and situations, from parents to peers to individual learning with computers.

Finally, apprentices and children had a very personal relationship with their parents and their masters. This personal relationship vanished with the school, where a teacher had the responsibility to teach many students and assumed authority over them. Teachers were not able to know each individual student very well and his particular needs and problems. The relationship was much more impersonal than in the apprenticeship era. The use of computer-aided learning environments will allow a much more interactive and direct way of learning, although personal contacts will be reduced, and personal and emotional aspects cannot be dealt with in the same way.

All in all, CH suggest that "[p]erhaps the most striking change from the apprenticeship era to the schooling era was the state's assumption of responsibility for educating children. In the current era, people interested in getting ahead are taking back responsibility from the state" (CH 2010, p. 24). In consequence, the authors perceive a

[7] With regard to higher education, Peter Drucker has controversially gone farther, suggesting that "[t]hirty years from now the big university campuses will be relics. Universities won't survive. It's as large a change as when we first got the printed book." […] "It took more than 200 years (1440 to the late 1600s) for the printed book to create the modern school. It won't take nearly that long for the big change" (Drucker 1997).

weaker influence of the state in the future, so that its role in the provision of the public good of education will decrease. Although the new era might have many benefits in the future, it may also pose important challenges. For example, social cohesion and equity may be negatively affected because every individual can learn according to his own values and wealth. Public schooling allowed the creation of common values for a nation and the acquisition of a relative high level of education available to all parts of society. For example, Milton Friedman stressed the essential role of public schooling for creating a democratic society (Friedman 1962). A reduced influence of the public school could potentially threaten the basic existence of the state: the power of interests groups and the impact of the wealth of parents could have much stronger implications for the future career because popular (financial) support for the school is dwindling. Educational inequalities might become more accentuated.

Similarly, the idea of public education, as the acquisition of a broad set of skills and worldviews that may be useful in a variety of professional contexts, may be hampered by parents wishing a much more focused education for their children. These children may be less open to new and alternative ideas and points of views. On the other hand, there may be individual empowerment in education, so that every individual has more choice, can learn in a customised way and has more responsibility over his education. The increasing availability of MOOCs (i.e., Massive Open Online Courses) illustrates the choice and opportunities that are beginning to unfold for learners. Traditional learning institutions such as the school and university systems have to adapt. They are slowly and tentatively adapting to this new era.

Thus, learning as such may become key in the future. In the same spirit, Toffler already pointed out many years ago that "[t]he illiterate of the 21st Century will not be

those who cannot read and write, but those who cannot learn, unlearn, and relearn" (Toffler 1971, p. 414).[8]

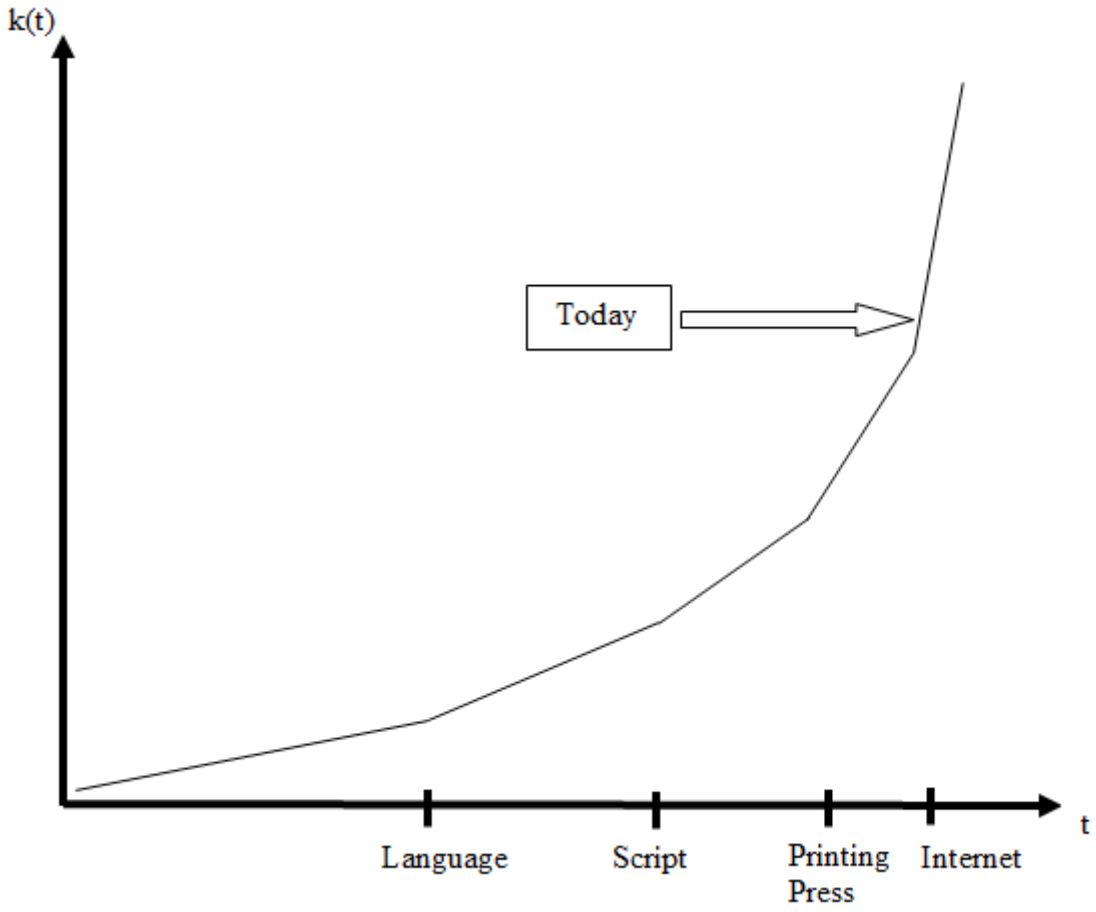
4. The four stages of knowledge production in history

Toffler may have been right in his historical comparison. Indeed, literacy has been relatively low among humans throughout history until the 20th century. For example, the share of individuals in the world who were able to read and write was less than 10 % in 1750 (Cipolla 1969). In the area of knowledge production, we can go even further back in time than in the area of education. Thus, we can characterise different stages in the very long run. These different epochs are language, the script, the printing press and the internet. Figure 3 gives a very rough and simplified schematic illustration of this long-run process, where *t* represents time and *k* represents knowledge. It illustrates that we might potentially again be at the beginning of a new (knowledge) era.[9]

[8] In a sense, his idea mirrors the concept of intelligence. The question, what intelligence truly is, is still very hotly debated. Sternberg is widely cited in this context, defining intelligence as "comprising the mental abilities necessary for adaptation to, as well as selection and shaping of, any environmental context" (Sternberg 1997, p. 1030).

[9] The distinction of these areas follows the ideas of McLuhan (1962) and Harnad (1991).

Figure 3 Schematic representation of worldwide long-run knowledge production



First, the 'invention' of language may distinguish humans from animals.[10] The invention of language took place some 100,000s years ago. It gave humans the ability to communicate effectively and to pass knowledge to the younger generations by oral means. Language was also the foundation of the evolution of culture. Still, speech is slower than thought and thus slower than the biological possibilities given by the human brain (Harnad 1991).

Second, writing was invented some 10,000s years ago. It allowed the preservation of knowledge on a longer run. Knowledge could be disconnected from the presence of a speaker or hearer who were necessary in the channel of oral knowledge transmission.

[10] Note that more recent research suggests that animals can also communicate in a more complex manner than previously assumed. Therefore, the distinction between humans and animals in this point becomes ever blurrier.

Compared to the oral tradition, knowledge in a written form is more systematic, precise and reliable. In contrast, knowledge transmission is slower, less interactive and less spontaneous than speech. In other words, speaking is faster than writing. Whereas a speech can be heard by many individuals at the same time, the written word can be read only by one person at a time (Harnad 1991).

Third, the printing press revolutionised the scale, scope, cost and speed of writing. The costs of the production of knowledge decreased sharply, the speed increased tremendously and the number of written publications rose exponentially (Harnad 1991). Thus, knowledge could be preserved and stored much more easily and cost efficiently. Therefore, "the printing press changed the conditions under which information was collected, stored, retrieved, criticized, discovered, and promoted" (Dewar 1998). In this sense, the printed word restored a part of the interactive element lost in the process of writing because written communication and the exchange of ideas and knowledge became much quicker and easier (Harnad 1991).[11] In addition, it was the first truly large-scale 'one-to-many' communications medium (Dewar 1998).[12]

What is common to these first three major steps in the evolution of knowledge is that they changed the qualitative way of thought. Harnad proposes that "speech made it possible to make propositions, hand-writing made it possible to preserve them speaker-independently, and print made it possible to preserve them hand-writer-independently. All three had a dramatic effect on HOW we thought as well as on how we expressed our

[11] Still, one has always to consider that not only knowledge was spread but also many errors and myths, in particular during the first hundred years of its invention (Rosaldo 1981). However, the ultimate effects on knowledge production and conservation were more important. Similarly, the internet is now a major platform for the diffusion of myths (Gilster 1997, Crawford 1999, Bawden and Robinson 2000), but one may suggest that the consequences on knowledge are again more significant. Clearly, other content is also diffused through the internet such as pornography, which finds its counterpart in similar printed forms at the beginning of the printing age (Eisenstein 1979, Bawden and Robinson 2000).

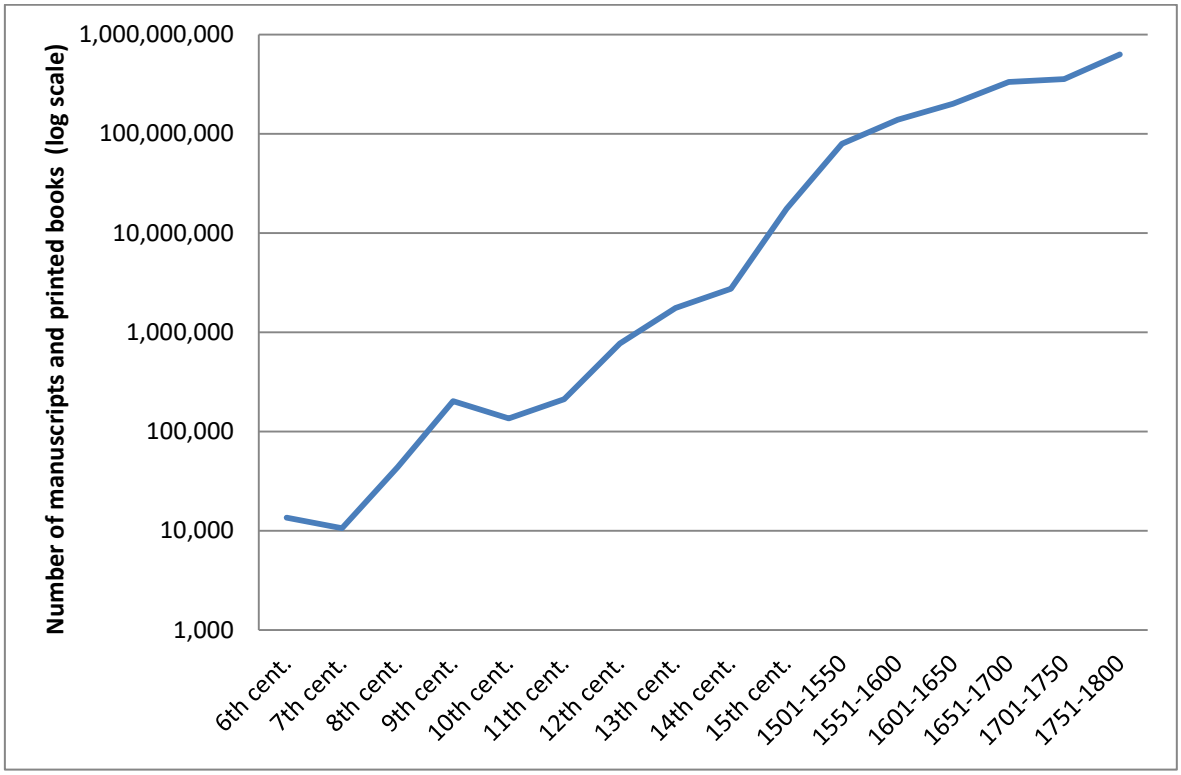
[12] Note that Dewar's (1998) and Dewar and Ang's (2007) work is to an important part based on Eisenstein (1979). Other authors suggest a less important impact of the printing press, such as Johns (1998). See also Eisenstein (2002) and Johns (2002) for a more thorough discussion.

thoughts, so arguably they had an equally dramatic effect on WHAT we thought" (Harnad 1991).

A series of inventions followed, such as the typewriter, photocopier and the telephone, but the fourth major step in the production and transmission of knowledge has only come about due to the invention of the internet. The internet allows the storage of (almost) infinite amounts of knowledge independent of place and time. The speed of knowledge transmission is also tremendously faster as knowledge can be accessed instantaneously online. The reader can, depending on the form of knowledge, react to it in real time and give feedback or develop further the presented ideas. Thus, speed is significantly increased along with the scope and interactivity. This is the consequence of its quintessentially being the first truly large-scale 'many-to-many' communication medium (Dewar 1998).

Some other major changes from writing to printing to the internet may be highlighted. However, it is essential to keep in mind that it is always important not to overemphasise possible analogies with past evolutions. Still, some comparisons may allow some insights and give tentative lessons for the current transition. To begin with, the preservation, updating and dissemination of a document have been greatly improved in each phase. For example, only relatively few handwritten documents were produced over many centuries (see Figure 4). Manuscript production in western Europe increased over time but totalled only less than 3 million documents in the 14th century. Any handwritten copy was always different from its predecessor. In addition, errors in copying manuscripts occurred many times and these errors were often propagated to subsequent versions which added further errors.

Figure 4 Book production in western Europe, 6th century to 1800



Source: Own presentation, data by Buringh and van Zanden (2009).

With the printing press, the number of books exploded which greatly facilitated the dissemination of a work, not only to the few existing scholars but also to the general public. Considering Figure 4, one can see that there is a huge increase in book production after Gutenberg's printing press, with almost 80 million books within the first fifty to hundred years after its invention in the middle of the 15th century. Therefore, the printing of a high number of (almost) identical copies also ensured the correct preservation of a text. Note, however, that the quality of works degraded in the first decades after the invention of the printing press. The reason was the rapid profit seeking by printers, so that errors in manuscripts were quickly replicated. In contrast, the large diffusion of the works meant that these errors were identified and corrected in the medium run (Eisenstein 1979, Bawden and Robinson 2000). In fact, editors used the possibility to solicit corrections from readers, which developed into a common procedure to improve documents. Therefore,

feedback was an important element. In this way, printed works were regularly improved and 'updated' from one edition to another (Dewar and Ang 2007).

The internet changed the rules once again. Already an important part of human knowledge, which was previously only available in handwritten or printed form, is now available electronically.[13] Preserving knowledge is greatly enhanced due to the interconnected network characteristic of the internet because it is built on the connection of many independent servers. In contrast, printed paper was first perceived to be more ephemeral than handwritten parchment, leading to a reduced preservation period of a text. Still, after some time it became clear that a large number of a printed text was the best way to protect it from complete destruction (Bawden and Robinson 2000). In comparison to digital copies, paper may be destroyed rather easily. Time may also deteriorate paper quality and content. On the other hand, electronic content is unaffected by time. Once something is online it may be difficult to remove it entirely and for all times. The network nature also means that limiting content and thus censorship is more difficult, although some countries attempt it. The preservation and dissemination of any type of content – not only texts and images, but also other multimedia types such as sounds and videos – is, therefore, enhanced.[14] Getting and giving feedback is also much easier and faster (Dewar and Ang 2007). This might counteract the concerns about the quality of online materials that have not been professionally quality controlled or peer-reviewed as in the traditional print media (Eisenstein 1979, Bawden and Robinson 2000). Whereas it may take more than a year (generally between 3 and 12 years in many cases) from the printing of one

[13] For example, Hilbert and López (2011) consider information and show that digitally stored information was already more widespread than analog information in 2007.

[14] Hilbert (2014) analyses the content of the recent explosion of information between 1986 and 2007. Interestingly, he finds that there has not been a multimedia but a text and still image revolution. In other words, although all types of contents increased exorbitantly throughout the period, the relative share of text and still images increased remarkably. The switch from the analog to the digital age has boosted texts and still images, not the reverse. At least until now.

edition to another, updating can be done in much shorter intervals. In addition, online content may be updated by linking it to new digital contents (Dewar and Ang 2007).

Moreover, knowledge retrieval has involved quite different techniques. Before the printing press, the ability to memorise information was very important. Different mnemonic methods were invented to help individuals. Book indexes did not yet exist or were not fully or systematically implemented (Dewar 1998). For this reason, it was common that scholars had to travel between different locations of knowledge (e.g., monasteries and universities) to retrieve knowledge. Thus, it was the time of the 'wandering scholar' (Bawden and Robinson 2000).

The printing press allowed the production of a much higher number of books. Book printers followed the demand of consumers who wished to have better indexed books. For this reason, the composition of a book became much more systematic. Features such as title pages, tables of contents and numbered pages were only systematically introduced with the printed form of the book. As a consequence, books were more precisely categorised, giving rise to elaborated bibliographies and book catalogues. Furthermore, some of the most important issues of general knowledge were stored by new encyclopaedias. The retrieval of knowledge was, thus, made much easier and systematic (Dewar 1998). In consequence, scholars did not have to wander to the same extent as before but were transformed to more 'sedentary scholars'.

The internet has been the newest breakthrough. (Almost) any kind of knowledge can be accessed anywhere at any time. Therefore, similar to the move from written texts to print, physical distance is once again overcome in the quest for knowledge. In this sense, knowledge comes to the user (including the scholar) and not the other way round (Bawden and Robinson 2000). The bibliographies and book catalogues of the past are now part of search engines. The importance of these search engines is not surprising given their

historical equivalents. As the internet expands, their importance will probably further increase. Similarly, encyclopaedias have been replaced to a large extent by their online homologue, Wikipedia.[15] However, in both cases, i.e., search engines and Wikipedia, full-text search is much more powerful and time-saving than earlier indexes (Dewar 1998). Thus, it is no surprise that "[s]earch engines have a crucial role in shaping how we now perceive the world and the top hit for almost any search is often a Wikipedia page" (Pfister 2009, p. 218, referring to Halavais 2009).

Another major concerns the ownership of knowledge. Before the printing press, the notion of intellectual property did not exist or only rudimentarily. The actual author of a written document could often not be identified with certainty. The Bible is one example. In many cases, works were attributed to an author. The invention of printing brought about a new era in intellectual property rights. However, at the beginning this did not concern authors. In fact, the rights (in modern terminology, copyright) were given to individual printers. Only later on the intellectual property rights of authors were recognised. As their authorship was now acknowledged and preserved for the future, some authors might have been incentivised to write books for the sake of immortal fame. In the current age, copyrights (and other rights) can be much more easily circumvented as the economic cost of limitless reproduction and distribution of a work are almost non-existent. In the printed book world such an endeavour involved a range of important costs (Dewar 1998). In consequence, the protection of copyrights is an ongoing issue. At the same time, in some areas authors either put their artistic content in the public domain or contribute work without explicitly being named as an author (such as in Wikipedia's articles).

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[15] Note that Wikipedia contrasts sharply to traditional encyclopaedias in the way knowledge is produced. Whereas traditional encyclopaedias rely on experts and editors for their entries, Wikipedia relies on 'participatory expertise', i.e., everybody can write an article and edit it. Thus, "[t]his model of participatory expertise challenges traditional information routines by elevating procedural expertise over subject matter expertise and opening up knowledge production to the many" (Pfister 2009, p. 217).

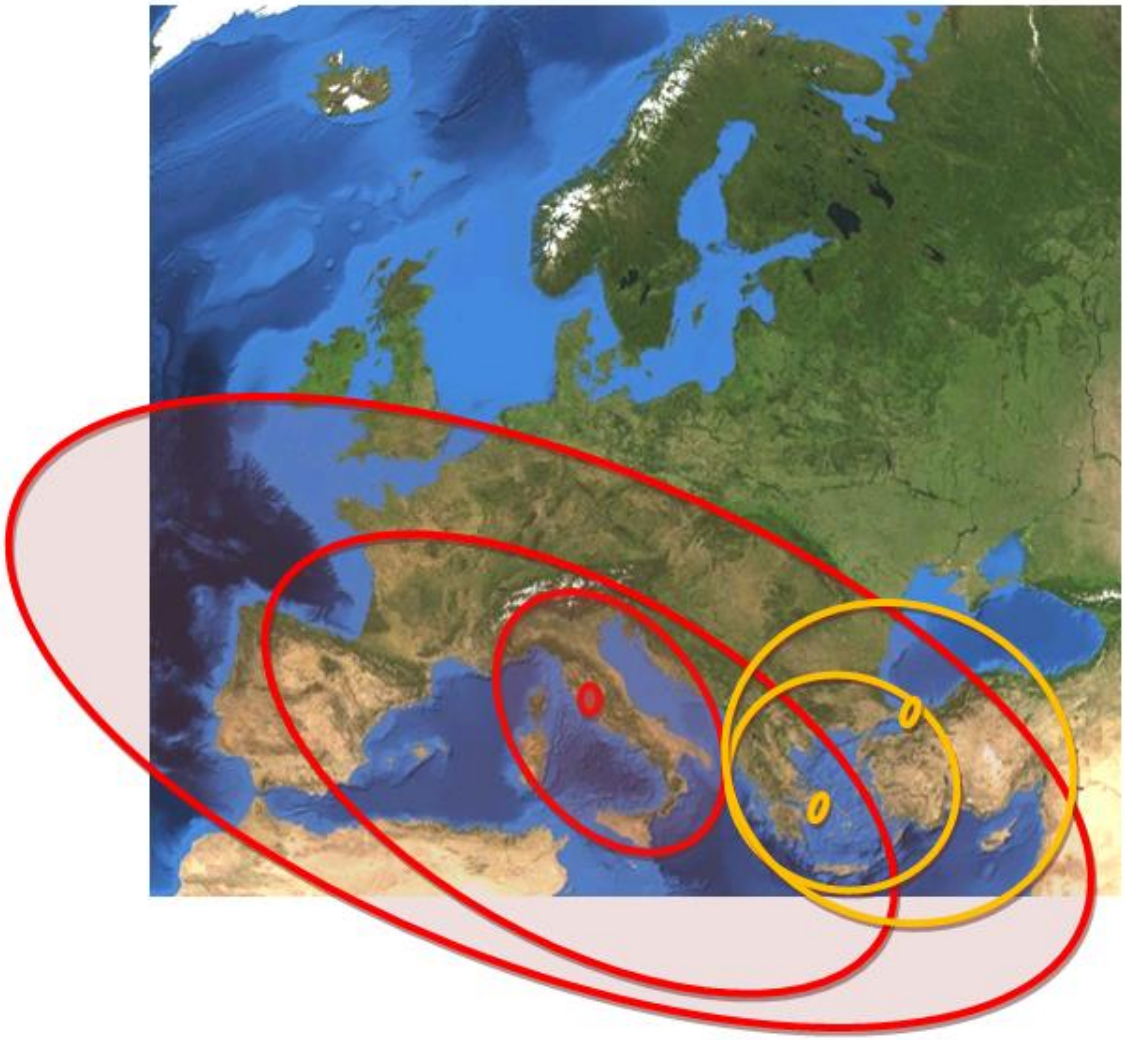
Finally, the acquisition of knowledge has been transformed profoundly. Knowledge was to an important part acquired through the means of memorisation before the printing press, as few were able to read and written texts were relatively scarce. Lectures and manuscripts were read (aloud). Apprenticeships also featured a significant role of memorisation of practices. The idea to learn from books only appeared in the larger society with the printed word. It was also a change in societal perception: whereas the reading of books was formerly attributed to the older generation, children were now introduced to books and used them as a means of knowledge acquisition at an early age. In other words, knowledge acquisition was transformed from listening to reading. The switch from the oral culture, where all knowledge was only 'alive' if it was memorised by heart, to the written culture is apparent. The acquisition of knowledge became also more individualistic and private, as the reading of a book does not need a teacher or mentor. Today, a new change is looming but the ultimate transformation has yet to be seen. Learners have been transformed from listeners to readers, and now the internet and computers allow to transform them into users (of content) or even 'doers' (who actively participate in the creation of new knowledge). Acquired knowledge is much more redundant in a variety of areas but at the same time it can be quickly updated online. Multimedia oriented forms of knowledge may also become more important. 'Just-in-time learning' might be a good way of putting the arising possibilities (Dewar 1998).

5. Transitions in human capital and their economic implications

What implications did fundamental changes in knowledge production have on the economy? While the invention of language and writing occurred thousands of years ago, we may get an idea from the large-scale and long-run changes involving the printing press. Accordingly, this knowledge transition occurred at first in Europe. In consequence, European countries (and later on their Offshoots) were the early leaders in the human capital and knowledge production characterising the modern world. For this reason, it might be worthwhile to reflect briefly on the characteristics that have shaped the geographical dimension of this transition.

In fact, there has been a major geographical shift in the leading countries in education over more than the last 2000 years (see Cipolla 1969). In many respects, this shift is related to the shift in economic prosperity throughout Europe. Those countries or regions that were most prosperous in the past often also invested most heavily in (elite) education. Clearly, if we go briefly through European history, the progress in Greece is generally seen as a first mile stone in the development of European culture. Greek civilisation was much more advanced than those in other parts of Europe. Later on, the Romans conquered large parts of Europe and brought their own culture and civilisation to many of the modern states of Europe. Rome was the crucial centre of this civilisation. Over time, Constantinople also became an important economic and cultural centre in the Roman Empire. With the split of the Roman Empire it became the undeniable centre of the remaining Eastern half, whereas the Western half collapsed. If we want to consider the regional dimension of human capital from the time of the Roman period to the Printing Press, we could imagine a regional distribution of human capital that is similar to a core-periphery model with Rome at the centre (and with Greece and later Constantinople as important Eastern centres) (Figure 5).

Figure 5 Regional human capital distribution from classical times onwards



Source: Own illustration, map by Wikimedia Commons (2007).

As can be guessed from the shape of the circles, the idea is to give a very rough notion of how regional differences in such a core-periphery model could have looked like. Evidently, these circles do not represent any clear demarcations of regional human capital and are not correct in any more specific sense. Rome and Italy might have naturally been at the core of this model and the further one moves to the periphery and the limits of the Roman Empire, the lower are the human capital values. The differences between those border regions that were part of the Roman Empire and those that were not, might have

been striking. For example, Cipolla (1969) notes that school density was relatively high in the Roman Empire.[16] Teachers were available in almost any location. In contrast, the Germanic tribes outside the empire were mainly illiterate and did not share the positive Roman attitudes towards education. As a consequence, literacy levels decreased significantly after their invasion. The only organisation that upheld the values of education and saved parts of the literate culture was the Church. However, the disintegration of the empire led to the major influence of military elites, and the military was rather opposed to 'fine' education. Famous military men such as William the Conqueror and Charlemagne were illiterate (Cipolla 1969, Logan 1986). Therefore, in the Germanic territories "people deem it useless or base to instruct anyone unless he be made a clerk" (Wipo, 'Tetralogus', as cited in Pertz 1853; Cipolla 1969, p. 41) and possibly believe also that "letters are removed from manliness and the teaching of old men results for the most part in a cowardly and submissive spirit" (Procopius, see Grundmann 1958; Cipolla 1969, p. 41). This contrasts sharply with the later German and Scandinavian attitude towards education. In a nutshell, the Roman culture may have been broadly characterised by literacy and the Germanic culture by illiteracy. An interesting case are those countries where both cultures existed, such as France. France was divided between a more 'Germanic' North and a more 'Roman' South. A line could be drawn in France, illustrating the more illiterate culture in the North and the much more literate culture in the South. Again, the same line could be drawn many centuries later – only that now the North would be the literate region and the South the illiterate one (Cipolla 1969, see also Furet and Ozouf 1977, Hippe and Baten 2012).

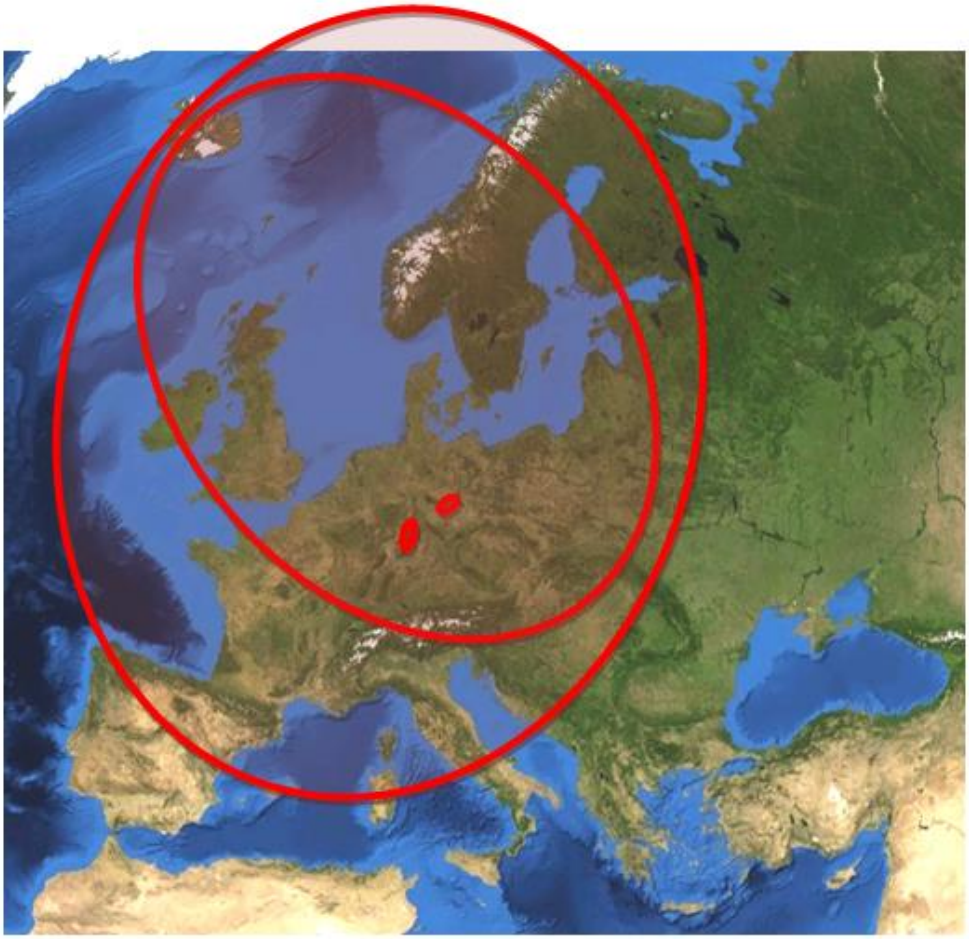
Therefore, there was an apparent reversal of educational traditions and a reversal of fortunes in the long-run history of Europe. What might have brought about this dramatic

[16] The following descriptions are mainly based on the fundamental work by Cipolla (1969).

change? One possible cause of the reversal may have been the combination of Gutenberg and Luther. The importance of Protestantism for the formation of human capital has often been reinvigorated (e.g., Weber 1958), most recently by Becker and Woessmann (2009) and others. Interestingly, Cipolla notes that a movement towards higher literacy levels had already existed before Luther's teachings. This movement could (at least in part) have been a consequence of the lower book prices brought about by Gutenberg's invention of the printing press. For example, the *Lübecker Postille* wrote already in 1493: "shame on those who cannot read and thus disregard the salvation of their souls… shame on those avaricious persons who do not care to buy books which one can buy now at a low price" (Hajdu 1931, Bach 1961, cited in Cipolla 1969, p. 49). The stress on education may have been much more widely diffused by Luther but the move towards education had possibly existed before – and was potentially caused by the printing press.[17] Gutenberg's invention made books and literacy much more meaningful and accessible to ordinary men. Luther's ideas could then have been rather a consequence of these earlier precedents.

[17] Correspondingly, Cantoni (2010) and Dittmar (2011) find that Protestant cities and cities close to Wittenberg did not grow more than Catholic cities after the invention of the printing press.

Figure 6 Regional human capital distribution after Gutenberg/Luther



Source: Own illustration, map by Wikimedia Commons (2007).

Taking Becker and Woessmann's (2009) notion of the importance of distance to Wittenberg for education (and including Mainz as the initial centre of the printing press invention, similar to Dittmar 2011), we could imagine the following core-periphery model (Figure 6). This model developed as a consequence of Gutenberg/Luther and was largely in place at least until the 20th century (if not until today in some respects) (see Houston 2001, Hippe 2012, Hippe and Baten 2012, Diebolt and Hippe 2017a, b, Hippe 2013 for some illustrations). The former illiterate and uneducated Germanic tribes became the most educated peoples in Europe. Accordingly, the core-periphery in human capital may have moved from the centre of the Roman Empire (Rome) to Central Germany (Mainz-

Wittenberg). Clearly, these circles give some very limited information about the distribution of human capital after Gutenberg and Luther but the general tendency of human capital variables such as literacy can be highlighted in such a way.[18] If we take a simultaneous glance at both maps the shift in the regional distribution of human capital in Europe becomes more than evident. A transition that may have been importantly influenced by a new phase of knowledge production – inaugurated by the printing press – with major economic repercussions not only for Europe but the entire world. It may have been a precursor of the later broader human capital transition involving all parts of society and all countries in the world after the Industrial Revolution.

6. The growth of information and knowledge

Thus, the spread of knowledge has accelerated impressively due to the different stages of knowledge production, in particular the printing press and nowadays the internet. James B. Appleberry, president emeritus of the American Association of State Colleges and Universities, assumes that "[t]he sum total of humankind's knowledge doubled from 1750-1900. It doubled again from 1900-1950. Again from 1960-65. It has been estimated that the sum total of human knowledge has doubled at least every five years since then… It has been further projected that by the year 2020, knowledge will double every 73 days" (Appleberry 1992, see Breivik 1998, p. 1). While the foundations of such estimations are certainly quite debatable, they still may give a hint of the direction of knowledge production over the longer run.[19] For purposes of illustration, we may take these

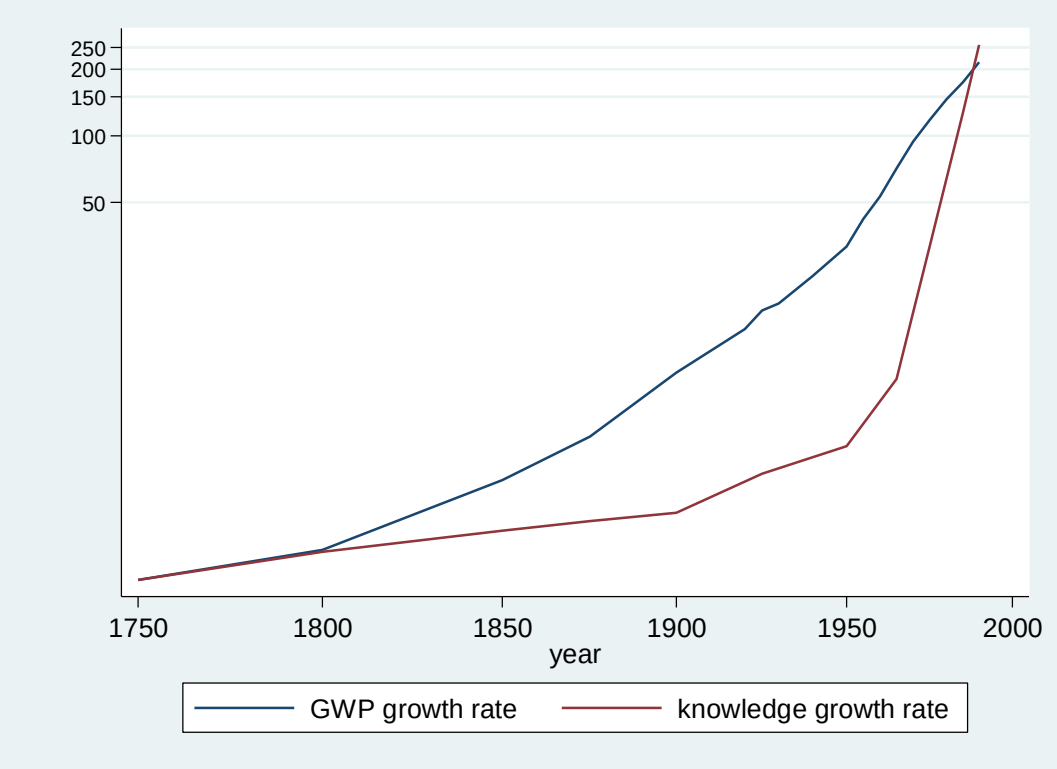
[18] This is also not to say that other factors apart from religion and geography did not also play a significant role in human capital formation (for example, land inequality was an important factor, see e.g., Baten and Hippe 2017).

[19] Unfortunately, the original source of the data has been lost (personal communication with Appleberry). The data are possibly based on Buckminster Fuller (1981) and the idea of a 'knowledge doubling curve'.

estimations literally[20] and combine them with estimations of world GDP (or more exactly, the gross world product, GWP) by DeLong (1998) until 1990. Interestingly, worldwide knowledge and GDP are estimated to have risen at the same rate until 1800. Subsequently, world knowledge increased by less than the growth rate of world GDP. Only in the last decades does world knowledge take off. It should have increased even much more rapidly since 1990. In this sense, 1990 would be the turning point in this history of economic growth and knowledge growth since the Industrial Revolution. Coincidentally, it is the time when computers (as a means of diffusing knowledge) made their widespread breakthrough. It might suggest the important role that knowledge might play in future growth. Still, one has to remember that these estimations are very rough so that only very tentative conclusions can be taken. But they may be valuable for thought experiments. Future research should attempt to provide more precise estimations.

[20] It is assumed that a doubling occurred during 1950 and 1965, the citation being not absolutely clear for the period 1950 to 1960.

Figure 7 Long-run growth of worldwide knowledge and GDP

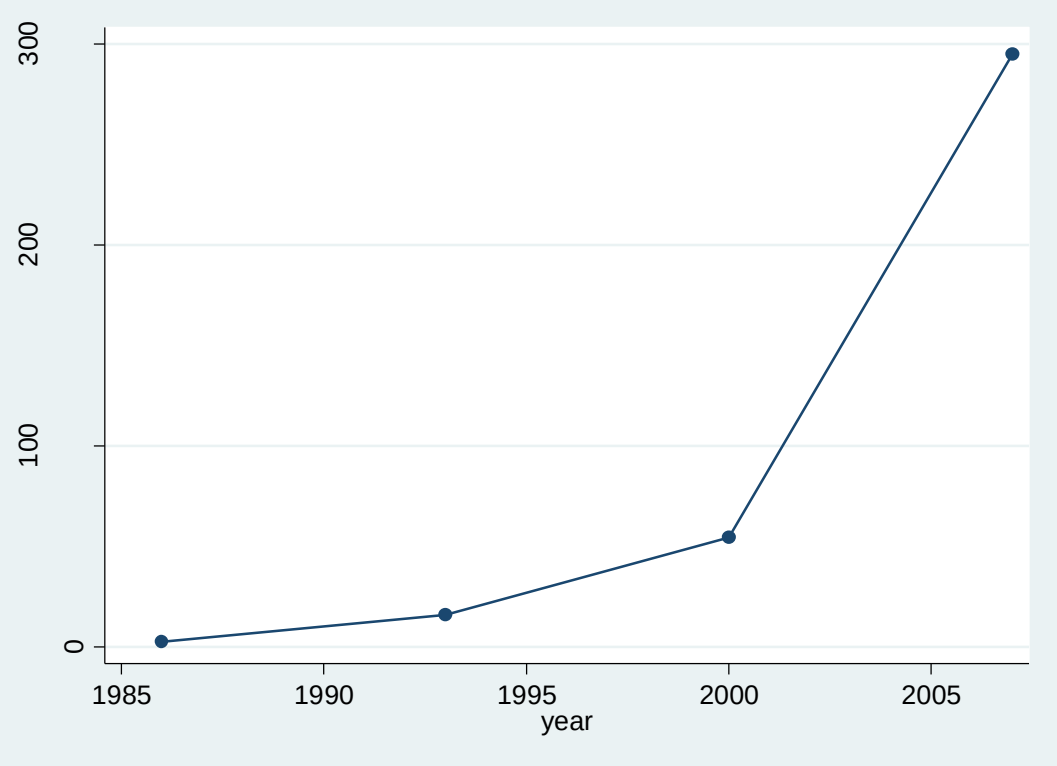


Source: see text.

More recently, Eric Schmidt, CEO of Google, has also referred to the incredible high new creation of information. In 2010, he claims that "[e]very two days now we create as much information as we did from the dawn of civilization up until 2003. […] That's something like five exabytes of data" (Techcrunch 2010). The historical compound of the estimate is clearly fascinating and revealing. However, there are also more serious and detailed (and verifiable) calculations, albeit only for the last years. Hilbert and López (2011)'s study, published in *Science* Express, estimates how much information has been stored in the most relevant analog and digital storage technologies between 1987 and 2007. Their estimates suggest an important increase from less than 3 (in 1987) to almost 300 exabytes in 2007 (see Figure 8). Note the sharp rise between 2000 and 2007, coinciding with the rapid diffusion of the internet and digital media. To have an idea of these figures,

the authors indicate what this would mean if all this information was stored on CD-ROM. In 2007, this would give a bit more than 400 billion CD-ROM and "[p]iling [them] up […] would create a stack from the earth to the moon and a quarter of this distance beyond" (Hilbert and López 2011, p. 62).

Figure 8 Total worldwide amount of information, 1987-2007



Source: based on Hilbert and López (2011)'s data.

Given the fact that we have progressed another decade, we can easily assume that we have gone still much further than the moon in the meantime. Whatever the actual numbers may look like, all of these different estimations give us an impressive vision to think about. It seems that the tremendous increase in information and knowledge may have a major impact in the way we live, work and learn in the future. The economy of the future will certainly be heavily influenced by these developments. The knowledge economy may

be ahead of us. Hopefully in the way Rooney et al suggest: "[k]nowledge is people doing things, knowledge economies are people doing things with better outcomes for more people" (Rooney et al 2012, p. 1).

7. Conclusion

This paper has put the knowledge economy in a larger perspective. In particular, it has shed some light on some of the major transitions and breakthroughs in the history of education and knowledge, allowing us an outlook into the future.

Thus, the paper has focussed on the very long-run evolution of human capital as incorporated in education and knowledge. More specifically, this evolution can be broken down into several stages or eras. We may be entering now a third phase of education. The first phase was characterised by the apprenticeship regime, the second one by mass schooling and the future one by life-long learning. In contrast, the evolution of knowledge has been characterised by a number of breakthroughs, in particular the 'invention' of language, writing, the printing press and the internet. Subsequently, we have indicated the relevance of this knowledge for the economy and the comparative long-term relationship between economic development and knowledge. Information and, eventually, knowledge have been exploding for the last couple of years thanks to the new information and communication technologies (ICT). This increase has certainly been more dramatic than increases in global wealth and prosperity. One might expect that this knowledge growth may pull economic growth in the future, although the specific outcomes would need much more thorough future research.

We are aware that the approach presented in this paper is certainly simplistic and does not acknowledge the broader and more subtle socio-economic historical evolutions

which have changed much more gradually over time. In addition, the idea of certain epochs does not mean that transitions from one epoch to another did not exist – in fact, it was quite the contrary. For example, the fact that the internet has been invented does not mean that books have already vanished or will vanish in the foreseeable future. Different knowledge technologies and forms of education have their specific and unique advantages which have to be considered as a whole. For this reason, they are often complements and not substitutes. Therefore, more research is still needed on these transitional phases, particularly because we are currently living in such a phase of rapid and fundamental change.

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