The origin of the "Knowledge Economy"

Helmut Ortner
Leopold-Franzens-Universität, Innsbruck

Various observers describe today's global economy as a "knowledge economy."[1] Everyone talks about it and much has been written about it. But what exactly does it mean? How did it evolve and in what sense can late eighteenth-century Europe be regarded as its place of origin? This article addresses various explanatory models and, out of this synopsis, presents the most convincing combination of pertinent lines of thought. It explains in what important ways the scientific revolution provided the exemplar for other major revolutions and which inner mechanisms of the resulting dynamic conglomerate were responsible for laying the basis on which today's knowledge-based economy could develop. The article will also show how game-theoretical methods provide a deeper understanding of some of these developments' core aspects. The paper concludes with a discussion of some challenges the knowledge-based economy's breathtaking success story poses to today's society and to the people who live in it.

1. Introduction: Knowledge and the Knowledge-based economy. What is it?

The term "knowledge-based economy" and related expressions already appear in discussions about "post-industrial" society's structure dating from the 1960s.[2] But it is only in more recent years that knowledge has entered the general visual focus of economic research.[3] The production of knowledge, its accessibility, and the capacity to use it[4] have

[1] Skyrme, *The Global Knowledge Economy and its Implication for Markets* (1997).
[2] To name but a view, Lane talks about the "knowledgeable society;" compare the numerous references in e.g. Castells, *Das Informationszeitalter*, vol. 1 and 3 (2001 and 2003); Enterweb; *Knowledge Economy*, (2004); Drucker specifies the central function of knowledge for the economic and social actions of a society (see the historical survey of Wolff, *Auf dem Weg zur Wissensgesellschaft* (2000), p. 253, and Bell, too, argues in a similar way in his description of post-industrial society; Bell, *Die nach-industrielle Gesellschaft*, (1979), pp. 214 *et seq.*
[3] Wolff, *op. cit.*, p. 253.
[4] This general thought has been sub-categorized in many different ways; among other phenomena digitalization of value creation chain, virtualization of markets, decoupling of control and service, network effects becoming operative, increasing codification of knowledge, internalization of industrial R&D, rapid diffusion of electronic commerce,

increasingly come to be considered the driving forces behind successful modern economies and the most important wealth-creating asset[5] in today's so-called[6] "knowledge-based economy."[7] What is true on the aggregated level also holds for the single economic actor for whom successful "knowledge management" has become the decisive competitive weapon.[8] It took economic theory some time to respond to these developments.[9] Neo-classical economics did not recognize knowledge as a factor of production in its own right: knowledge was regarded as an exogenous factor in its models. Eventually, however, the

and many others have been identified and scrutinized (Picot and Fiedler, *Der ökonomische Wert des Wissens* (2000), pp. 15-17 *et seq.*; Goddard, *Editor's Preface* (1989), p. xvi; Knoll, *Progress towards the Knowledge-Based Economy* (2001), pp. 6-11.

[5] Also Landes defined knowledge as a decisive factor in determining the "wealth and poverty of nations." Compare Landes, *The Wealth and Poverty of Nations* (1998), p. 179, 187, 206, 276 *et seq.* "A knowledge-driven economy is one in which the generation and exploitation of knowledge play the predominant part in the creation of wealth." That idea-driven innovation cycles are important factors determining an economy's position in the global hierarchy is now common wisdom. This is what the World Bank Report 1999/2000 refers to when stating: "The balance between knowledge and resources has shifted so far towards the former that knowledge has become perhaps the most important factor determining the standard of living." Also see Advisory Group 1999, Skyrme, *op. cit.* (1997), United Kingdom Department of Trade and Industry, *Our Competitive Future,* (1998) and McGovern, *Information Wealth* (1998).

[6] Castells has labeled the modern techno-economic system "informational capitalism" (Castells, *op. cit.* [2001], pp. 19, 83-84) and "informational global economy" (Castells, *op. cit.* [2003], p. 386); the difference between the terms "information" and "knowledge" will be discussed below.

[7] Picot and Fiedler, *op. cit.*, pp. 15, 21, 32, explain that the resource knowledge is becoming more and more important in comparison to the classic physical factors of production and refer to it as the "decisive factor of success". Müller, *Fallen wir durchs Netz?* (2000), pp. 39-41, states that with the Industrial Revolution the main focus moved from agriculture to manufacture and industry and in the recent past we experienced the shift from the industrial towards the knowledge-based economy. Wolff, *op. cit*, p. 253, also considers knowledge to be a new factor of production besides the classic ones. See also Knoll, *op. cit.* 2. Enterweb, *op. cit.* refers to knowledge as "the key factor of production." See also Romer, *Increasing Returns and Long-run Growth* (1986); Romer, *Endogenous Technological Change* (1990) and OECD, *Communications Outlook 2001* (2001).

[8] One consequence of this is the development of knowledge management programme and the appointment of CKOs (Chief Knowledge Officers) in many businesses; see Skyrme, *op. cit.* (1997) and Report of the Advisory Group of the Minister for Information Technology of New Zealand, *The Knowledge Economy* (1999).

[9] Hepworth, *Geography of the Information Economy* (1989), pp. 5 *et seq.*

godfathers of New Growth Theory attempted to incorporate knowledge into their models.[10] This was done specifically with an eye towards explaining long-term economic growth – an issue with which traditional economic models have had difficulty. It is primarily the Stanford economist Romer who refined the neo-classical model further, defining knowledge as an intrinsic variable functioning as a primary engine for economic growth and leading to sustained increasing marginal returns on technological investment.[11]

In this article I expressly refer to knowledge, rather than information, as the core concept. Knowledge is understood to be information further processed and made applicable to achieve certain aims;[12] it thus transcends the notion of information,[13] which is often closely associated with ICT

[10] See also the related thought in Castells, *op. cit.* (2001), 34 that for the first time in history the human intellect is not just an element in the production system but a direct productive force.

[11] This is contrary to traditional economics which predicts that there are diminishing marginal returns on investment. New Growth theorists like Romer, however, resort *inter alia* to phenomena such as non-rivalry and platform effects of new technology (which develops out of a broad and dynamic knowledge base) to justify their results. See e.g. Romer, *op. cit.* (1986); Romer, *op. cit.* (1990); Advisory Group, *op. cit.* Romer built his theory on insights based on the work of economists such as Schumpeter and Solow.

[12] In this paper the term "knowledge" only refers to "useful knowledge" (Kuznets). A term used by Kuznets, *Economic Growth and Structure* (1965), pp. 85-87 to denote the source of modern economic growth. He used the term interchangeably with "tested" knowledge that is potentially useful in economic production. This is the narrower notion in comparison to Mokyr, *The Gifts of Athena* (2002), pp. 2 *et seq.* and Machlup, *Knowledge* (1980-84), vol. 2, p. 10, who just demand from knowledge to be "practical" or capable of making contributions to material welfare to qualify as "useful knowledge". Thus the "testing" or "truth" of knowledge is not considered to be a relevant criterion. It is the latter – broader – notion which forms the basis for the following discussion.

[13] I will not discuss all the different layers of terms and concepts developed by semiotics and communications sciences, such as "signs," "data," etc (see e.g. Eco, *Einführung in die Semiotik* (1972), pp. 32 *et seq.*) One should, however, bear in mind that the notions of sign – data – information constitute an afferent cascade of complexity. Whereas a sign represents the most basic element, defined by Montagu as a "concrete denoter" possessing an inherent specific meaning (see also *Encyclopedia Britannica*, DVD-edition 2001, s. v. "sign") "data" codes signs in a meaningful context (Wahren, *"Wissensmanagement" und "Lernende Organisation"* 2000, p. 280). For being labelled information, this data has to be integrated into a "higher" context of relevance where it has the status of a "difference" or piece of news; This is why Bateson, *Geist und Natur* (1983) famously defined information as "the difference that makes a difference". Against this background, the distinction briefly drawn in the main text can be elaborated as follows: Information can be defined as an explicit, well-structured and codified (Lundvall, *Information Technology*

(Information and Communication Technology) and which I consider too narrow a focus for the subject of this article.[14] After presenting an explanatory model of how knowledge as defined above functions as the core driving force behind persisting economic growth, I shall show how ICT and education can be understood as (mere) elements within this larger framework and that thus neither should be taken *pars pro toto.*

2. Historical roots of the knowledge-based economy

The success story of the knowledge-based economy and its companion, the long-running economic growth phenomenon, is closely connected to the so-called Industrial Revolution of the mid-eighteenth century and to the question why it endured beyond the early-nineteenth century. There had been earlier clusters of great revolutionary inventions, most notably in the fifteenth century with the emergence of movable type, the casting of iron, and advances in shipping and navigation technology. But before the Industrial Revolution, the economy was subject to negative feedback: each episode of growth ran into some obstruction

in the Learning Economy (1997)) set of signs with specified significance and with relevance for achieving a certain aim; *Picot* and Fiedler, *op. cit.*, p. 16; also compare the definition of Weigl, *Zur Rolle der Information in der Wirtschaft* (2003), pp. 11-12. For information to become knowledge it has to be integrated into a "higher" context (see e.g. Kurzweil, *Homo Sapiens* (1999), pp. 147 *et seq*) of relevance consisting of specific empirical patterns. It could thus be defined as interweavement (Picot and Fiedler, *op. cit.* [2000], p. 16, call it "networking of information") and condensing of information by humans (Wahren, *op. cit.*, p. 280) which enable the carrier to apply and utilize it in order to carry out specific actions. Knowledge is not just the result of piling information but rather of processing this information by (an) individual(s) against the background of her/their experiences and interpretations; Picot and Fiedler, *op. cit.*, p. 16; Wolff, *op. cit.*, p. 254. This is why Knoll, *op. cit.*, p. 2, rightly states that the notion of "knowledge" has a much broader scope as the one of "information" because the former includes practical skills and competencies.

[14] There is a number of authors who focus on "information" (Shapiro and Varian, *Information Rules, op. cit.*, p. 3), "information society" (Castells, *op. cit.*, pp. 1, 19, 83, 84), or have a primarily ICT-related focus (Picot and Fiedler, *op. cit.*, p. 17); see also Hepworth, *op. cit.*, p. 7. Wolff, *op. cit.*, p. 253 *et seq*, is right to criticize that in too many discussions the equalization of information and knowledge "creeps in, which is wrong." And so is Knoll, *op. cit.*, p. 5, stressing that the notion of the knowledge-based economy is "an extended version of the information society, which has focused on information and ICTs.

or resistance that put an end to it.[15] Growth occurred in relatively brief spurts which punctuated long periods of stagnation or mild decline.

There were several feedback mechanisms which were operative over the centuries, but only a few representative ones will be mentioned here to illustrate the idea. The best known of these negative feedback mechanisms are Malthusian traps, i.e. they are concerned with the problem that rising income creates population growth which in turn is restricted by the resulting pressure on fixed natural resources.[16] The Industrial Revolution's effects on agriculture ("agricultural revolution")[17] helped to escape the serious resource constraints which Smith, Malthus and others in the eighteenth century believed placed an insurmountable limit on persistent economic growth. Two other examples of negative feedback mechanisms will be discussed in more detail: a narrow epistemic base of techniques (sub 2.1), and institutional negative feedback (sub 2.3). We shall show how other related revolutions (scientific, industrial, and military revolution), too, helped to overcome them for the first time – and how an understanding of this process can be further enlightened by game theoretical reasoning.

2.1 The narrow epistemic base of techniques. Throughout most of human history one pivotal root of the problem of diminishing marginal returns was the narrow epistemic base of technology. New knowledge appeared in a haphazard and unpredictable manner.[18] From time to time, new techniques were discovered fortuitously, but because of their narrow epistemic base they rarely led to a continuous stream of extensions, refinements or new applications. It was the scientific revolution that laid the corner-stone for further developments which

[15] Mokyr, *op. cit.*, p. 31.

[16] The now-famous notion of the Malthusian trap was first described by its 'patron saint' the English economist T.R. Malthus in his *Essay on the Principle of Population as it affects the future Improvement of Society* (1798). See Livi-Bacci, *A Concise History of World Population* (1997), p. 82; Jay, *Road to Riches or The Wealth of Man* (2000), pp. 147 *et seq.*, 382 *et seq.*; Landes, *op. cit.*, p. 187.

[17] See Encyclopedia Britannica, DVD-edition 2001, s. v. "The 19th-century power revolution on the farm".

[18] Mokyr, *op. cit.* (2002), p. 1.

resulted in a major shift, paving the way for permanent, self-sustaining economic growth.

2.1.1 The scientific Revolution: It is not so much about the substantive novelties... During the fifteenth, sixteenth, and especially the seventeenth century, scientific thought underwent a revolution. Often, the notion "scientific evolution" is associated primarily with progress as regards content, especially in the physical sciences: the names which are usually given in this context include Copernicus, Tycho, Kepler, Galileo and Newton.[19] The real breakthrough – not only for the purposes of this paper – however, was of another sort. Copernicus is often referred to as having given the starting signal for the scientific revolution in 1543.[20] Placing the sun, not the earth, at the centre of the cosmos – and thus challenging the traditional geocentric picture of the universe[21] – was indeed a major innovation.[22] But more was at stake than physics and astronomy, for the implications of the Copernican system struck at the very bases of contemporary society's worldview,[23] attacking the Dantean cosmos as well as the Aristotelian hierarchy of social place, political position and theological gradation. Further landmark discoveries by Tycho Brahe (abandoning Aristotle's crystalline spheres and his doctrine of heavenly perfection)[24], Galileo (using

[19] For a more complete overview of the "revolutionaries" see Fischer, *Die andere Bildung* (2003), pp. 50 *et seq.*

[20] In this year he finished his great work "De revolutionibus orbium coelestium libri" (Six Books Concerning the Revolutions of the Heavenly Orbs). Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of the scientific revolution".

[21] Sagan, *Unser Kosmos* (1980/1997), pp. 68 *et seq*; Hawking, *Die illustrierte kurze Geschichte der Zeit* (1988/1997), pp. 6 *et seq.*, Fischer, *Aristoteles, Einstein & Co* (2000), pp. 70 *et seq.*

[22] His system had a simplicity, coherence, and aesthetic charm that made it irresistible to many, although it was not unchallengeable since it did not solve all the difficulties of the Ptolemaic system. No known physics could answer these open questions, and the provision of such answers was to be the central concern of the scientific revolution. Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of – the scientific revolution".

[23] Knobloch, *Copernicanische Wende* (2004), pp. 89 *et seq.*

[24] This Danish scholar actually was a supporter of the traditional view but made important discoveries, unwittingly providing data that ultimately contributed to deciding the argument in favour of the paradigm shift. Tycho moved the centre of revolution of all other planets to the sun. To do so, he had to abandon the Aristotelian crystalline spheres that otherwise would collide with one another. Tycho also cast doubt upon the Aristotelian doctrine of heavenly perfection, for when, in the 1570s, a comet and a new star appeared, Tycho

the newly invented telescope),[25] and Kepler (formulating new planetary laws)[26] helped shatter these ancient foundations. And then there was the experimental and mathematical genius[27] of Newton who justified Copernicus, Kepler and Galileo with his new physics presented in his "Principia" (1687)[28] – often referred to as the symbol of the scientific revolution.[29] The consequence of all this was that a new view of nature emerged, replacing the Greek one that had dominated science for almost

showed that they were both above the sphere of the moon. This was also a blow to the conventional wisdom of his days that change could only happen in the sublunary sphere because although earth has been corrupted by the fault of man, the rest of the universe was still perfect and therefore could not change. Sagan, *op. cit.* (1980), p. 69 *et seq*; also see Landes, *op. cit.* (1998), 210; Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of the scientific revolution".

[25] He announced in quick succession that there were mountains on the moon, satellites circling Jupiter, and spots upon the sun. Moreover, no one had suspected the existence of countless of stars the Milky Way was composed of until Galilei saw them. Tignor, *et al, Worlds Together, Worlds Apart* (2002), p. 182. Fischer, *op. cit.*, pp. 101 *et seq.*, Hawking, *op. cit.* (1988), pp. 6 *et seq.*, p. 22 *et seq*; Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of – the scientific revolution".

[26] At the same time Galileo was searching the heavens with his telescope, in Germany Kepler was searching them with his mind. His new planetary laws could explain the movements of the planets much better, assuming that they are not circular but elliptical, that the sun is located in one of the two foci of the ellipse, and that planets do not move at a constant speed; they accelerate as they move toward the sun. Sagan, *op. cit.* (1980), pp. 65 *et seq.*, Hawking, *op. cit.* (1988), p. 6; Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of – the scientific revolution". Fischer, *op. cit.* (2000), pp. 120 *et seq.*

[27] It was this combination which enabled him to establish both the Copernican system and a new mechanics. Newton's new physics applied equally well to terrestrial and celestial bodies. Newton's three laws of motion and his principle of universal gravitation sufficed to regulate the new cosmos. Every object will remain in rest or move in a straight line unless some force has an effect on it. Equal force produces equal effect. For every action there is an equal opposite reaction. Objects are attracted to each other with a force that is directly proportional to the mass of the objects and inversely proportional to the square of the distance between the objects. See Tignor *et al.*, *op. cit.*, p. 182; Hawking, *op. cit.* (1988), pp. 7 *et seq.*, 22 *et seq.*, 44, 50 *et seq.*, Hawking, *Das Universum in der Nussschale* (2001), p. 111, Bryson, *A Short History of Nearly Everything* (2003), pp. 73 *et seq.*, p. 453. Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of the scientific revolution".

[28] "Philosophiae Naturalis Principia Mathematica" (Mathematical Principles of Natural Philosophy); Bryson, *op. cit.*, p. 72 *et seq.*, p. 178.

[29] There were similar attempts to criticize, systematize, and organize natural knowledge that did not lead to such dramatic results, such as Andreas Vesalius' *De humani corporis fabrica* ("On the Fabric of the Human Body", called the *De fabrica*), a critical examination of Galen's anatomy, and the flurry of anatomical work it touched off, as well as similar attempts in other sciences (see Encyclopedia Britannica, DVD-edition 2001, s. v. "science, history of the scientific revolution").

two thousand years.[30] By the end of this period, it could even be said that science had replaced Christianity as the focal point of European civilisation[31] – a most fundamental change

2.1.2...but about the new "scientific methodology". The last remark suggests that emphasing the new substantive knowledge these scientists produced or discovered would be too narrow a focus: the scientific revolution was more than that. Especially in the context of the subject of this article, the pivotal novelty was not so much the new knowledge as regards content *per se,* but rather the simultaneously developing "scientific method". Francis Bacon is said to be the father of this new way of thinking and searching for new insights: "Method is the key to knowing".[32] If the right method were applied, discoveries and insights would follow inevitably. This was the real breakthrough, as it laid the basis for further unbroken progress for centuries, as will be shown below sub B: it is thus worthwhile to examine it more closely.

The core of Bacon's philosophy of science was an account of inductive reasoning given in such works as "The Advancement of Learning" (1605) and Book II of "*Novum Organum*" (1620).[33] The defect of all previous systems of beliefs about nature, he argued, is to be found in an inadequate treatment of general propositions from which deductions were made. They either were the result of precipitate generalisation from one or two cases, or they were uncritically assumed to be self-evident on the basis of their familiarity and general acceptance[34]. In order to avoid hasty generalisation, Bacon urges a technique of "gradual ascent," that is, the patient accumulation of well-founded generalisations of steadily increasing degrees of generality.

[30] See Tignor *et al., op. cit.*, p. 182.

[31] Encyclopedia Britannica, DVD-edition 2001, s. v. "physical science – the scientific revolution".

[32] Landes, *op. cit.*, p. 203; see also p. 201.

[33] Russel, *Philosophie des Abendlandes* (1945/1997), p. 551; Encyclopedia Britannica, DVD-edition 2001, s. v. "Bacon, Francis, Viscount Saint Alban (or Albans), Baron of Verulam – The new method".

[34] He, thus, anticipated very recent developments in modern scientific methodology, pointing at the dangers produced by fallacies based on phenomena like "selection bias" or "availability heuristic" (a field of research decisively spurred on by the path breaking works of Kahneman and Tversky; just compare Tversky and Kahneman, 'Rational Choice and the Framing of Decisions', *op. cit.*, p. 251.).

This method would have the beneficial effect of loosening the hold on men's minds of ill-constructed everyday concepts that obliterate important differences and fail to register important similarities. The crucial point, Bacon realised, is that induction must work by elimination and not, as it does in everyday life and in the defective scientific tradition, by simple enumeration.[35] He devised tables,[36] or formal devices for the presentation of singular pieces of evidence, in order to facilitate the rapid discovery of false generalisations. What survives this eliminative screening, Bacon assumed, may be taken to be true. He thus promoted the inductive method of carefully-controlled, empirical testing.[37] Bacon believed that modern man could gradually comprehend the general principles of nature's manifold operations and thus bend nature to man's will: "Knowledge is power."[38]

Despite its manifold still-existent flaws[39], Bacon's approach provided

[35] Thus he stressed "the greater force of the negative instance" – the fact that while "all A are B" is only very weakly confirmed by "this A is B," it is shown conclusively to be false by "this A is not B." This is evocative of Popper's emphasis on "falsification" instead of "verification" (Popper, *The Logic of Scientific Discovery* (1934)): Popper was of the opinion that it is impossible to verify or even confirm a universal scientific theory with any positive degree of probability. All that can be done is to disprove a universal theory. Whilst no number of observations can confirm a hypothesis only one observation will refute a hypothesis. Thus was born the concept of falsifiability where positive proof is ever beyond us.

[36] Bacon presents tables of presence, of absence, and of degree. Tables of presence contain a collection of cases in which one specified property is found. They are then compared to each other to see what other properties are always present. Any property not present in just one case in such a collection cannot be a necessary condition of the property being investigated. Second, there are tables of absence, which list cases that are as alike as possible to the cases in the tables of presence except for the property under investigation. Any property that is found in the second case cannot be a sufficient condition of the original property. Finally, in tables of degree proportionate variations of two properties are compared to see if the proportion is maintained. See Russel, *op. cit.* 1945/1997, p. 552; Oliver, *Die Geschichte der Philosophie* (1998), p. 67.

[37] Tignor *et al., op. cit.*, p. 182.

[38] This is the most common translation of Bacon's famous motto "Ipsa scientia potestas est" (*Meditationes Sacrae. De Haeresibus.* 1597).

[39] Bacon's attempt was still flawed in a number of aspects. To give just one example, many critics have accused him of failing to recognize the indispensable role of hypotheses (Delius *et al., Geschichte der Philosophie von der Antike bis heute* (2000), pp. 32 *et seq*) and of adopting a naive and unreflective view about the nature of causes, ignoring their possible complexity and plurality (pointed out, e.g., by John Stuart Mill; see Encyclopedia Britannica, DVD-edition 2001, s. v. "Bacon, Francis, Viscount Saint Alban (or Albans), Baron of Verulam – The new method") as well as the possibility that they could be at some distance in space and time from their effects. Another weakness, not sufficiently emphasized, is Bacon's preoccupation with the static.

a solid basis for the further development of a sophisticated scientific method[40], constituting a framework and a methodology for systematically acquiring knowledge by investigation and experiment. From these, tentative conclusions can be drawn (so-called hypotheses) which are then either strengthened over the course of time or falsified.[41] The result is a steady increase of knowledge.

The conception of a scientific research establishment, which Bacon developed in his utopia, *The New Atlantis*, proved to be an equally seminal contribution to the future development of science. Here the idea of science as a collaborative undertaking, conducted in an impersonally methodical fashion and animated by the intention to give material benefits to mankind, is set out with literary force.[42] The practical impact of this thought is evidence of Bacon's enduring significance in "set[ting] the course for the development of the western world."[43]

2.2 The economic consequences. To explain what forces were set free by the development described above, Mokyr introduces the notion of propositional knowledge (symbolised by Ω, *episteme*) on the one hand, and prescriptive knowledge (symbolised by ?, *techne*) on the other hand.[44]

2.2.1 Interactions between ?- and Ω-knowledge and diminishing marginal returns. The significant and decisive dynamics which ultimately gave rise to the knowledge-based economy developed from a two-fold interaction between these two kinds of knowledge. The first interrelation is as follows:[45] an existing body of Ω-knowledge "maps" into a set of instructions that determines what a certain economy can do. This resulting

[40] Fischer, *Die neue Ordnung des Wissens* (2004), p. 155, pp. 176 *et seq*; Höffe, *Kleine Geschichte der Philosophie* (2001), p. 300.

[41] See Patzelt, *Einführung in die Politikwissenschaft* (1997), p. 49 *et seq.*, Seiffert, *Einführung in die Wissenschaftstheorie 1* (1996), p. 153 *et seq.*, Popper, *op. cit.* (1934); Popper, *Conjectures and Refutations* (1963), pp. 33-39. There is also a very good presentation in the first chapter of Junker *et al*, *Evolution* (2001).

[42] Russel, *op. cit.*, p. 550, Fischer., *op. cit.* (2000), p. 86 *et seq.*, Fischer, *op. cit.* (2003), p. 63 *et seq.*, Fischer, *op. cit.* (2004), p. 176 *et seq.*

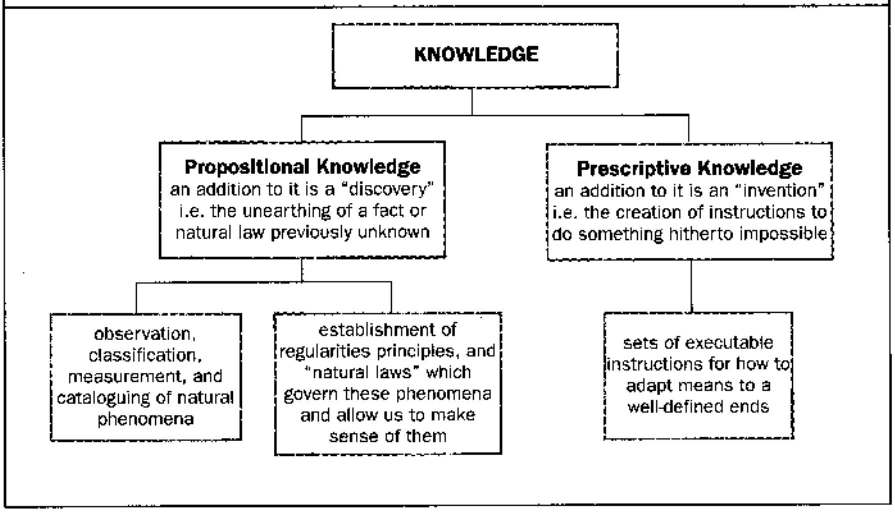
[43] Delius *et al.*, p. 32.

[44] Mokyr, *op. cit.* (2002), pp. 4 *et seq.*

[45] Mokyr, *op. cit.* (2002), pp. 13, p. 16.

?-knowledge is the set of feasible techniques, sometimes known among economists as "the book of blueprints".[46] In this way, an existing technique (?) can be said to have an epistemic base in Ω. The wider and deeper the epistemic base on which a technique rests, the more likely it is that a technique can be extended and find new applications. The narrower the epistemic base in Ω of a particular technique, however, the less likely it is to keep on growing and expanding after its first emergence, because further expansion would demand more and more fortuitous events.[47] Indeed, much technological progress before 1800 was of that very nature: although many important new techniques appeared before the Industrial Revolution, they had too narrow an epistemic basis and thus rarely, if ever, led to continued and sustained improvements after the initial 'stroke of luck'. The widening of epistemic bases after 1800, however, signals a phase transition or régime change in the dynamics of useful knowledge.[48] This was a crucial shift because, only if the useful knowledge base does not expand, will the economy eventually run into diminishing returns. However, as long as there is a continuous increase in useful knowledge,

FIGURE 1. Two kinds of knowledge



[46] For this, Mokyr uses the symbol ?'. Among these feasible techniques, only some are selected for actual execution – denoted by Mokyr as ?".

[47] Mokyr, *op. cit.* (2002), pp. 14, 18, 19.

[48] Castells, *op. cit.* (2001) pp. 1, 34, 40, 41; Mokyr, *op. cit.* (2002), pp. 19-20.

the ceiling on prosperity growth can permanently be pushed further. It is the generation of new Ω-knowledge which is the fuel that keeps the engine of growth running.[49] This was precisely what the new scientific method provided a tool for: for the first time in human history there was a method capable of producing such a constant flow of new Ω-knowledge.[50] And because the epistemic base did expand continuously, technological progress was not bound to slow down this time.

There is a second and equally important interrelation between the two types of knowledge:[51] not only is a broad Ω-basis essential for keeping the continuous stream of new ?-knowledge flowing, but ? can also produce feedback into Ω.[52] This is what Castells calls a 'cumulative feedback-spiral' of innovations and their application."[53] In the simplest case, a technique is discovered by chance and the fact that it works reveals a regularity or pattern which can be registered in the realm of Ω whose growth is thereby further stimulated.[54] What is more, changes in techniques also open up new opportunities in the form of new instruments and laboratory methods, making completely new research possible.[55] This double positive feedback form ? to Ω is capable of leading to virtuous cycles which are much more powerful than can be explained by technological progress or scientific progress alone:[56] the successive sets of Ω not only grow but provide wider and wider epistemic bases for ?, which in turn lead to increased sets of Ω. Feedback from technology

[49] Mokyr, *op. cit.* (2002), pp. 283, 285.
[50] Knoll, *op. cit.*, p. 4.
[51] Landes, *op. cit.*, pp. 284, 285 calls it the "marriage of science and technique."
[52] Knoll, *op. cit.*, p. 14. See also the examples in Mankiw, *Principles of Economics* (2001), p. 229.
[53] Castells, *op. cit.*, pp. 1, 84.
[54] Landes, *op. cit.*, p. 191.
[55] Mokyr, *op. cit.* (2002), p. 20 *et seq.*
[56] The result can be described as a kind of social contact between "knowers" and "doers;" Tignor *et al.*, p. 220. The bridges between the "savants" and the "fabricants" became wider and easier to cross; Mokyr, *op. cit.* (2002), pp. 54, 69. This is extremely important as there is too much tacit and uncodifiable knowledge in technology for the written word and the graphical representation to do it all; Mokyr, *op. cit.* (2002), p. 63; so-called tacit knowledge is knowledge gained form experience, rather than knowledge instilled by formal education and training; Advisory Group, *op. cit.* (1999); see also the related idea of "hybrid" or dual careers in Kranakis, *Hybrid Careers and the Interaction of Science and Technology*, *op. cit.*, (1992), pp. 177-204.

to propositional knowledge and *vice versa* is what made the continued evolution of technology the sustainable norm rather than the ephemeral exception. This combination and interplay is what ultimately drives the huge acceleration of innovation and technological breakthroughs which has the power to sustain impressive long-term economic growth.[57]

All this enabled the miracle of the Industrial Revolution to take place, the true economic significance of which is to be found not so much in the great inventions of the years between 1760 and 1790 as in the described self-sustaining process of innovation which, for the first time, was able to avoid running into diminishing returns and fizzle out after 1800 or 1820. In the pre-1750 environment, despite periods during which societies experienced clusters of important macro-inventions, technological progress had always failed to generate sustained economic growth. But in late eighteenth-century western Europe, "the Baconian programme reached a critical mass"[58], providing an engine for economic growth which has been running like clockwork ever since, without depending on mere randomness and chance as its casual fuel. Consequently, the 1820s witnessed yet another "wave" of inventions and conceptual breakthroughs, which created a "second wind"[59] that prevented the process from slowing down and petering out. This series of so-called micro-inventions[60] or "waves of gadgets"[61], which often could be turned into successful business propositions, led to the second industrial revolution,[62] an early incarnation of a basic pattern of making new useful knowledge work which is still operative today.[63]

Another mid-nineteenth-century invention reinforced this development: the industrial R&D lab[64], "the greatest innovation of the

[57] Landes, *op. cit.*, pp. 187, 200; Mokyr, *op. cit.*, pp. 23, 24, 56, 96, 102.
[58] Mokyr, *op. cit.* (2002), p. 286.
[59] Mokyr, *op. cit.* (2002), p. 84.
[60] Landes, *op. cit.*, p. 206.
[61] Mokyr, *op. cit.* (2002), p. 71.
[62] Landes, *op. cit.*, p. 284. 1860 is said to mark the beginning of the second Industrial Revolution. Concerning the significance of the rise of statistics as a way of interpreting information about the physical world for the formalization of empirical regularities in natural phenomena, see e.g. Mokyr, *op. cit.* (2002), pp. 72, 101.
[63] See Baumol, *The Free-Market Innovation Machine* (2002).
[64] Knoll, *op. cit.*, p. 6.

time"[65] in the "technology of generating technology," appeared for the first time in the 1860s in the German chemical industry.[66] It rapidly spread through other industries and provided an institutional framework which ensured that propositional and prescriptive knowledge kept reinforcing each other and provided the economy with a continuous stream of innovations which "gathered force to become a veritable torrent."[67] This development has been labeled "routinisation of research,"[68] "institutionalisation of innovation,"[69] and – even more tellingly – "the invention of invention."[70] All this was not only able to avoid the negative feedback mechanism mentioned at the outset but eventually even tipped the balance to provide a powerful positive feedback mechanism.[71]

2.2.2 Promethian growth. This is closely related to another basic dichotomy denoting an important factor of the major shift we have just described: the transition from extensive to intensive economic growth. It is only the former, based on an increase in inputs, which is doomed to run into diminishing marginal returns. In contrast, intensive growth relates to the rise in per capita output and thus means improved productivity. This type of growth can be a result of the benefits of increased specialisation and trade (Smithian growth) or it can be driven by a constant stream of scientific and technological innovations (Promethian growth). As has become clear in this section of the paper, it was the latter kind of intensive growth whose appearance made the decisive difference. Promethian growth is the "highest" form of economic growth, the only one which has the potential of developing a dynamic that leads to permanent, self-sustaining economic growth.[72] Everything

[65] Mokyr, *op. cit.* (2002), p. 85.
[66] Wolff, *op. cit.*, p. 257 states that the traditionally most important motive for the creation of new knowledge, curiosity, has since then more and more been replaced by the effort to answer concrete practical questions.
[67] Mokyr, *op. cit.* (2002), p. 85.
[68] Landes, *op. cit.*, p. 201.
[69] Mowery *et al., Paths of Innovation* (1998).
[70] Landes, *op. cit.*, p. 45.
[71] Landes, *op. cit.*, pp. 187, 191; Mokyr, *op. cit.* (2002), p. 33; Hepworth, *op. cit.*, p. 2.
[72] Landes, *op. cit.*, p. 187.

said so far can be understood as an explanation of the mechanics and the functioning of this type of economic growth and an explanation as to why knowledge lies at the core of this kind of persistent growth. This is why the "knowledge economy" is so telling. Understanding its deep meaning and inner logic means understanding an important constitutive element of the world in which we live.

The first and second Industrial Revolution constituted a stage in which the weight of the knowledge-induced component of economic growth (Promethian growth) increased markedly.[73] What has been called the third Industrial Revolution, the rise of the computer and the enormous progress in ICT has further stimulated and, above all, accelerated the process. This will be dealt with briefly later (sub 3.1).

2.3 Negative institutional feedback. The phenomena just described partly explain why economic dynamics eventually reached a stage where they became self-sustaining, thereby overcoming the empirical regularity, observed in former times, that economies have always been running against an absorbing barrier of technical stagnation. At some stage, the momentum that gathers behind technological advance usually exhausted itself. But now, for the first time, an intrinsic mechanism able to overcome "Cardwell's law,"[74] stating the historical truth that highly technologically creative societies usually only remain so for a relatively short span of time, has developed.

But this is only half the story. Throughout history there have also been external factors hostile to overly dynamic economic, and consequently social, developments – especially in the shape of so-called negative institutional feedback. Why did this second negative feedback mechanism not also become operative this time? Why were these dynamics not interrupted at some point from the outside?

[73] This was especially important since this was a period in which continuous political disruptions must have reduced the importance of "Smithian (trade based) growth;" Mokyr, *op. cit.* (2002), p. 30.

[74] Mokyr, *The Lever of Riches* (1990), pp. 207, 261-9. Mokyr, Cardwell's Law and the political economy of technological progress (1994). His "law" is based on an interpretation of Cardwell, *Turning Points in Western Technology* (1972), who recognized the phenomenon itself without giving an explanation for it. Cardwell's law does also have other facets which will be mentioned later.

2.3.1 Why did negative institutional feedback occur throughout history? When dynamic economic developments took place over extended periods of time, they usually generated social and political forces that, in almost dialectical fashion, terminated them. Prosperity and success led to the emergence of predators and parasites in various forms and guises who "eventually slaughtered the geese that laid the golden eggs."[75] This is evocative of Jay's "waltz motif"[76]: The first step is an economic advance which, in the second step, provokes predatory threats. Unfortunately the result of this, the third step, was seldom a social/political solution which maintained progress, but it was rather an attack against the innovations by those in power who were afraid of losing their power.

2.3.2 Doves and hawks. In human societies, there are always a couple of "hawks" ready to kill the "doves", should they suddenly pose a threat to them through changing circumstances. These are terms used in a specific game theoretical variant, called the Hawk-Dove Game.[77] This is a fascinating application of game theory which is based on evolutionary concepts. It was first applied to evolutionary processes by Smith[78] and can also be applied to the situation in hand.

The basic setup of the game matrix looks thus:[79]

TABLE 1. Hawk-Dove Game (1)

	Hawk	Dove
Hawk	(V-C)/2, (V-C)/2	0, V
Dove	V,0	V/2, V/2

[75] Mokyr, *op. cit.* (2002), p. 31.
[76] Jay, (2000), pp. 15 *et seq.*, 199 *et seq.*, 289 *et seq*; with special regard to China, p. 95 *et seq.*, p. 121, and India, p. 100.
[77] O'Gorman, *Game Theory* (2003), Prestwich, *Game Theory and Evolutionary Stable Strategies* (1999).
[78] Smith, J. M., *Evolution and the Theory of Games* (1982). He also included a third type of behaviour, the so-called bourgeois strategy, and showed that this would be more stable than either pure hawk or pure dove. A "bourgeois" may act like either a hawk or a dove, depending upon some external cue.
[79] V = value of the resource; C = cost of fighting. Should two doves meet, they get an average payoff of V/2. When a hawk meets a dove the hawk takes everything (V), the dove gets 0. When a hawk meets another hawk they fight, which involves a 50/50 chance of getting V and a 50/50 risk of injury (C); so the average payoff will be (V-C)/2.

Human society is considered to be made up of a mixture of "hawks" (individuals with power and who are ready to fight in order to keep it) and "doves" (individuals without power and who have no ability or willingness to fight). When two "birds" confront one another, "hawks" will fight until one is maimed, killed or flees, whereas "doves" will merely posture a little but will leave before any serious harm is done. Doves cooperate while hawks do not. In the case of a conflict, a hawk will always win against a dove. Under certain (plausible) assumptions[80], there will be a "mixed" Evolutionary Stable Strategy (ESS) with a quota of doves and hawks.[81]

Transition periods are very tricky for the established élites. Any period of rapid growth and change develops a dynamic which is potentially dangerous for the ruling class or the currently powerful social groups.[82] Social disruption is a function of change; technological progress inevitably involves losers.[83] New knowledge displaces existing skills and threatens incomes: technological change leads to substantial losses sustained by those who own specific assets linked to the existing technology.[84] Society's hawk-forces, thus, tend to resist change because they have a vested interest in the status quo, thereby providing another explanation for the astonishing steadfastness of "Cardwell's law" throughout history, i.e. the observation that technological progress encounters resistance from various groups that believe they stand to lose from innovation. The ruling classes themselves intervened or powerful pressure groups tried to manipulate the political system to suppress successful, and thus dangerous,

[80] Only if V is greater than twice C, the doves will go extinct.

[81] Just compare the obvious social tension which results from the income inequalities depicted by the Kuznets curve, which refers to the transformation of an agricultural into an industrial society. As Kondratiev showed, this process is a revolving one, leading to Kondratiev cycles or "long waves" (e.g. the Industrial Revolution 1787-1842, the Bourgeois Kondratiev 1843-1897 and the Neo-Mercantilist Kondratiev 1898-1950; see De Greene, *Will There Be a Fifth Kondratiev Cycle/Structure?*, *op. cit.*

[82] Landes, *op. cit.*, p. 201.

[83] Mokyr, *op. cit.* (2002), pp. 232, 253, 264.

[84] Technological change is almost never Pareto-superior, most likely there will be losers. See Mokyr, *op. cit.* (2002), pp. 43, 232, 277, 278. But even it the change would be Pareto-superior it could still pose a threat to the interest of the ruling classes, should they gain much less than the others.

innovation.[85] Such struggles usually ended in the victory of conservative forces and tended to cement the status quo.[86]

2.3.3 A modified model. China is just one example – among many others[87] – of this phenomenon: the Sung Dynasty[88] introduced extensive reforms which led to massive intensive economic growth[89] and a whole range of technological breakthroughs[90] in the eleventh and twelfth centuries. But after the Mongols had overrun China during the thirteenth and fourteenth centuries, the newly founded Ming Dynasty was powerful enough to hinder the growth process; they reversed the Sungs' achievements in order to "stabilise" society. So the Ming Dynasty was sufficiently powerful to nip a real Chinese industrial revolution in the bud.[91]

[85] And this obstacle to progress is perpetuated by its own inner logic: even if it were possible to overcome the mentioned resistance of the hawks, sooner or later the progress of technology would in all probability still grind to a halt because the forces that used to support innovation become vested interests. In a purely dialectical fashion, technological progress created the forces that eventually destroy it.

[86] Krusel *et al.*, *Vested interests in a Positive Theory of Stagnation and Growth*, *op. cit.* (1996) have also showed that in a simple growth model, rational behaviour generates resistance and possibly the suppression of technological change.
Barber, *Resistance by Scientists to Scientific Discovery*, *op. cit.* (1962), pp. 539-56, gives another interesting explanation: knowledge systems are self-organizing systems that in many ways can be thought of in evolutionary terms; Mokyr, *op. cit.* (2002), p. 221. The idea of self-organizing decentralized systems, or "catallaxy" as Hayek (Hayek, *Law, Legislation, and Liberty* (1973-6), vol. 1, pp. 35-54; vol. 2, p. 108) has called it, is one of the most powerful and influential ideas of the modern age and perhaps the most important element in Adam Smith's thought. In science, one of the most typical self-organizing evolutionary systems, resistance to innovation by an established scientific and at times ideological status quo, has always bee strong; also compare Kuhn's theory of paradigm shifts: Kuhn, *The Structure of Scientific Revolutions* (1962); Pajares, *The Structure of Scientific Revolutions* (2004); Mokyr, *op. cit.* (2002), p. 222. Resistance to change is one of the selection criteria operating in a Darwinian system.

[87] One could also mention Russia, Japan or the Islamic world (Landes, *op. cit.*, pp. 54, 200, 201), which seemed to be another promising future world power but suffered the lack of governmental institutions independent from dominant family structures. Other examples of mechanization and use of inanimate power without producing an industrial revolution are given by Landes, *op. cit.*, p. 200.

[88] 960 *et seq.* C.E.

[89] In 1078 Sung China produced 125,000 tons of cast iron, an amount that was unmatched until the 1790's when Britain reached this level again.

[90] E.g. movable type printing (1000); paddle wheel ships (1130); water-powered textile machinery (1200); huge ocean going junks (1200); major breakthroughs in mathematics (1086); the blast furnace (1050) etc.

[91] See Landes, *op. cit.*, pp. 55 *et seq.*, 200.

Economists have used the term "rent-seeking" for the replacement of market decisions by government control or some other form of collective decision-making that benefits a small group or an individual.[92] It implies including "loss-avoidance"[93] in the concept of rent-seeking. Against this background, the scope of application of the hawks and dove-game could be extended accordingly by defining V, not only as the static value of the resource, but by including also the potential threat of permanently diminishing the hawks' V for the future. A hawk will thus not only fight to get its share of V that is currently available, but also to prevent changes in the environment which would in the future lead to a new set of circumstances in which V is of less value to the hawk-class than it used to be. The mixed ESS will then not only be stable regarding the number of doves and hawks in the society, but there would also be a kind of "intrinsic stability" concerning the nature of V for which to fight.[94] And if a make-or-break condition for the nature of V is assumed, the "old" type of V will prevail.

The only way of escaping this trap is that hawks would, for some reason, not want to truncate progress anymore, and would maybe even desire to stimulate it. For this to happen, it would be necessary to introduce an even bigger threat to their survival than the one which comes with change. This is exactly what happened in Europe.

2.4 Why was negative institutional feedback overcome?

2.4.1 Competition. The magic formula here is "competition."[95] It was competition between the European states which helped to overcome the

[92] Noll *et al., Mosaisches Recht im Licht moderner Ökonomie* (2004), p. 160.

[93] Mokyr, *op. cit.* (2002), p. 253.

[94] This would be the result of assuming that that the nature of V is a make-or-break condition of all the cells of interaction between doves and hawks which underlies the whole game. This would mean that whenever a hawk enters a specific cell (regardless of whether it would be alone, encounter another hawk, or a dove), it would either preserve the "old" nature of V or destroy any change happened.

[95] Landes, *op. cit.*, pp. 36 *et seq.* states that the European fragmentation gave rise to competition among European nations and that this "fragmentation made all the difference". Landes, however, uses the competition concept in a broader sense than Mokyr does, including "the contest for power within European societies" and not only between states. I will in this paper focus on the latter.

built-in tendency for conservatism present in centralized bureaucracies. The more centralised and powerful a bureaucracy, the more formidable the obstacles on the road to technological progress. More often than not, despotic rulers did all they could to enforce conformity and squelch attempts to be different. On the contrary, decentralised systems have tended on the whole to provide a more favourable environment for dynamic developments.[96]

Western Europe's advantage over large empires such as China, the Ottoman Empire[97] or Russia lay in its pluralism, its diversity and its fragmentation. In Europe – for a number of reasons[98] – no single country had an unrivalled position of hegemony. Although sometimes one player, especially the Habsburgs and France, was very close to establishing himself as the hegemonic power, no one succeeded in doing so in the end.[99]

This "world of competition and national jealousies"[100] which emerged in Europe had a threefold positive effect:

2.4.2 Rulers did not want to stop the process. Technological progress spurs on not only economic performance, but also military capability. This is why even arbitrary rulers discovered that, much as they might have disliked the disrupting effects of technological change, they could not risk falling behind in comparison with rival nations. Military and, consequently, political power was simply inseparable from industrial development.[101] There was constant pressure to improve in order to outdo the others; the incentives to invent (primarily for military reasons) and

[96] Mokyr, *op. cit.* (2002), pp. 238-239.
[97] Landes, *op. cit.*, pp. 54, 200, 201.
[98] To name but a view: another version of a "mixed ESS" leading to the existence of a handful of large powerful entities within the European state system; the fact that a number of European countries embraced the improvements of the military revolution simultaneously and could thereby not gain a decisive advantage over the others; the geography of Europe, which has a lot of natural borders; the fact that several of the big European states were also maritime powers, etc.
[99] As far as the Habsburgs were concerned, this was officially recognized by the Treaty of Westphalia in 1648, and with regard to France by the Treaties of Utrecht, Rastatt and Baden in 1713-1715.
[100] Mokyr, *op. cit.* (2002), p. 77.
[101] Mokyr, *op. cit.* (2002), p. 281.

to prosper economically (to have a wealthy people providing a rich revenue base for military expenditure[102]) were very strong.

They were strong enough to overcome the natural tendency of negative institutional feedback. The macro power structure in Europe was such as to convince the single states that it would be in their best interest not to smother but to invest in and encourage the new technologies and further research.[103]

2.4.3 Single rulers could not stop the overall process. Even if single rulers had stopped the process in their own domain, they would not have had the power to halt the development as a whole. This aspect, too, can be incorporated into the hawk-dove game by altering the condition that the nature of V must be a make-or-break circumstance for all cells of interaction, i.e. by assuming that cells are separate and independent with regard to the nature of V. This change substantially alters the basic matrix of the game. Whenever a dove enters an empty cell or encounters another dove, this could happen in an old V (Vo) or new V (Vn) environment. In the first case, it/they would bring about a change in V, the value of which is much higher than the Vo's with which the hawks are still dealing. As a result, the Vn environment will win over time under plausible assumptions.

To give an example: let us suppose the benefit of gaining V is +50, the benefit of losing V is 0, the injury from fighting is -100 and the cost of display (of a dove) is -10. The payoff to a hawk in hawk vs. hawk contest would thus be -25.[104] The payoff to hawks when they encounter doves would be + 50.[105] The payoff to doves when they encounter hawks would consequently be 0.[106] Finally, the payoff to doves when they encounter

[102] The amount of money needed to maintain powerful armed forces was enhanced considerably by developments of the "military revolution" which – together with the already discussed industrial and scientific revolutions – makes up an important triumvirate in the explanation of the origin of today's knowledge-economy.

[103] Mokyr, *op. cit.* (2002), p. 268.

[104] Presumptions: chance of winning = 50 percent. E (H,H) = (0.5 * 50) + (0.5 * -100) = 25 – 50 = -25.

[105] Presumptions: chance of winning = 100 percent, i.e. the contests are asymmetrical. There would be no costs for the hawks since they never lose and since the dove immediately retreats once it recognizes the hawk. E (H,D) = 1 * 50 – 0 = +50.

[106] Presumptions: No chance of winning. No costs to the dove since it immediately retreats once it recognizes the hawk: E (D,H) = 0 * 50 + 1 * 0 = 0.

doves is + 15.[107] The resulting payoff-matrix would look as follows, and equilibrium frequencies would be 0.583 for hawks and 0.416 for doves.[108]

Now assume that Vn which doves can create in any cell they enter, provided they meet no hawk there, would be 200, whereas Vo, which is valid whenever a hawk enters the scene, remains at 50. This would not only change the matrix and consequently also the equilibrium frequencies dramatically, but would also lead to a gradual prevalence of Vn. Technological progress would eventually prevail.

In Europe, too, the stage was set perfectly for a mechanism like this to become operative. No single arbitrary ruler could turn off the lights for the entire system; Europe did not have "all its eggs in one basket."[109]

2.4.4 Putting Cardwell's law out of action. Furthermore, the other aspect of Cardwell's law, the empirically proven fact that any single economy will inexorably eventually move to an absorbing barrier of technological stagnation, can be annulled through competition. It was again Mokyr[110] who showed that this regularity holds only for a single

TABLE 2. Hawk-Dove Game (2)

	Hawk	Dove
Hawk	-25/-25	+50.0
Dove	0.50	+15/+15

TABLE 3. Hawk- Dove Game (3)

	Hawk	Dove
Hawk	-25/-25	+50/0
Dove	0/+50	+90/+90

[107] Presumptions: chance of winning = 50 percent. Both doves will display essentially the same amount of time. The one that wins is the one that is willing to display for a longer period of time at this particular time. No injury cost, as doves are not violent. E (D,D) = 0,5 * (50-10) – 0,5 * -10 = + 15.

[108] Calculated with the computer simulation under http://www.holycross.edu/departments/biology/kprestwi/behavior/ESS/Hawk_v_Dove_Sim.f/example1.html.

[109] Landes, *op. cit.*, p. 39.

[110] Mokyr, *op. cit.* (1990), pp. 207, 261-9; Mokyr, *op. cit.* (1994).

closed economy but that it does not hold in a world in which a number of separate and open economies compete with each other.[111] In a world with multiple economies, Cardwell's law ultimately has not the power to stop the overall process, even if it holds for each economy separately.[112] Not only was there no nation within the European "state system" which was able to hold on to dominant leadership too long, but competition among these independent political entities also ensured that, as long as there was at least one nation that was truly creative, the others followed suit.[113] This, again, is consistent with the historical observation that political competition is conducive to technological progress.

2.5. The Enlightenment. It is equally important to point out another constitutive element which helped to pave the way for the revolutionary shift towards a truly knowledge-based economy of enduring growth: the Enlightenment. In former eras, the predominant attitude was that there is only a fixed quantity of knowledge and everything one can know has already been known and taught or revealed by untouchable authorities, such as God or great philosophers of the past (primarily Aristotle). What he says *(ipse dixit)* is thought to be the absolute truth – and consequently there is no need to investigate independently or to think any further. This was exactly the "self-incurred immaturity", man's "emergence" from which Kant declared to be the very nature of Enlightenment.[114]

[111] Mokyr, *op. cit.* (2002), p. 278.
[112] This mechanism of annulling Cardwell's law is still active today as was shown e.g. by Cantwell *op. cit.* In recent history, technological leadership has passed from Britain to the United States, and in very recent times it has for some time switched to Japan.
[113] Mokyr, *op. cit.* (2002), p. 276.
[114] Kant 1784. The basic attitude was that traditional authorities should not be trusted blindly; see Tignor *et al.*, *op. cit.*, p. 182. This is, of course, only a sketch of the role the Enlightenment played in this regard. It would be interesting – but go beyond the scope of this paper – to show who the salient features of the Enlightenment contributed greatly to the emergence of the knowledge-based economy. In the following I just pick out a few: (1) Scepticism against authorities and tradition but trust in rationality and empirical methodology to ascertain "truth:" It suffices to, again, point to Bacon's discussion of causes of human error in the pursuit of knowledge – "idols" – or to the famous cartesian approach of searching a really trustworthy basis for one's reasoning by sceptically questioning any existing, even if widely accepted, premise, leading to his proposal of his four methodological rules in his "Discourse on Method" (1637); see e.g. Weischedel, Die philosophische Hintertreppe (1975/1997), p. 114 *et seq.*; Zimmer, *Das*

But even if one had tried to emerge from this "immaturity," it would have been an extremely risky undertaking before the Enlightenment[115] (and even then to do so was often not at all easy). Much of the newly produced or newly discovered knowledge was hardly reconcilable with traditional views and authorities – an insurmountable obstacle for many centuries. The Enlightenment, however, brought about a change in conditions which was conducive to questioning traditional wisdom, and thus enabled new knowledge to gain ground. It created an environment in which more people were prepared to follow Kant's famous calling, which he put forward in his "Answer to the question: 'What is Enlightenment?'"[116]: *Sapere aude!* – because it became less dangerous to do so.[117] Thus the contribution of the Enlightenment in acting as a lever for the scientific revolution and all its further implications should not be underestimated. The roots of the prosperity brought by the society based on knowledge are to be found in the industrial revolutions of the eighteenth and nineteenth centuries. These industrial revolutions, however, were hastened by the intellectual changes of the scientific revolution and of the Enlightenment that formed the basis for holding sway over formerly overpowering institutional (religious, social and governmental) realities.[118]

Philosophenportal (2004), pp. 64 *et seq.*; Höffe, *op. cit.*, pp. 155; Russel, *op. cit.*, p.553. (2) Rationalism: reason is made the paramount human quality; not tradition or authority or faith – if there is a conflict, it is reason which should trump the others. (3) Universalism and Globalism: The emphasis is on the general rather than the particular, which was a strong incentive to find the general rules or laws of nature which govern the single events and thus fuel the pool of Ω, in order to fuel the pool of ?, in order to fuel Ω, in order to … (4) Optimism: the Enlightenment is future-oriented; the belief is that the world is getting better because well-founded knowledge will increase over time through the application of reason (based on the scientific revolution and the adoption of the scientific method) which leads to well-founded knowledge that will eventually displace superstition; Mokyr, *op. cit.* (2002), pp. 29, 59, 287. (5) Other important features were individualism and civilization (as opposed to savagery).

[115] Just think of Giordano Bruno and many others. See also Landes, *op. cit.*, p. 201.

[116] Kant, An Answer to the Question (1784/2005).

[117] Some rulers not only stimulated the process because this was the only way to remain part of the European power play but because they genuinely believed in the concepts and ideas of the Enlightenment (just think of Joseph II). See also Mokyr, *op. cit.* (2000), p. 82.

[118] Mokyr, *op. cit.* (2002), p. 297.

Mokyr[119] coined the term "Industrial Enlightenment" to denote and sum up the key features which represent the missing link between the scientific and the Industrial Revolution,[120] finally leading to the knowledge-based society. Its three independent phenomena present a synopsis of facts already discussed in other parts of this paper: (1) scientific method; (2) scientific mentality (3) scientific culture (this is the result of applying the scientific method with a scientific mentality, maintaining the constant interplay between Ω and ?). Against this background, it could be said that it was through the Industrial Enlightenment that the scientific revolution and the Enlightenment produced the Industrial Revolution and finally the knowledge-based economy as we know it today.

3. The presence

3.1. Access to and dispersion of knowledge. Today both kinds of knowledge keep on reinforcing each other and they do so more rapidly than ever before. One reason for this is that knowledge has an extremely high level of "tightness", i.e. the fact that knowledge can be easily accessed, is widespread and accepted.[121] The roots of this phenomenon, too, can be traced back to the eighteenth century.[122] Not only has the amount of knowledge increased inexorably ever since the Baconian revolution but, more or less contemporaneously with the Industrial Revolution, there were also advances in the organization, storability, accessibility and communicability of Ω, which resulted in a dramatic reduction in access costs:[123] new ways of cataloging useful knowledge (encyclopedias, dictionaries, textbooks, manuals and comprehensive

[119] Mokyr, *op. cit.* (2002), pp. 34 *et seq.*, 59, 287.

[120] The "missing link" exists because historians have generally not been able to support the notion that the scientific revolution led directly to the Industrial Revolution; Mokyr, *op. cit.* (2002), p. 36.

[121] Mokyr, *op. cit.* (2002), p. 6; Landes, *op. cit.*, pp. 276 *et seq.*

[122] Of course one could mention even earlier important inputs, such as Gutenberg's revolutionary invention of typographic printing in the 1450s.

[123] See Knoll, *op. cit.*, p. 6; Landes, *op. cit.*, p. 204; Mokyr, *op. cit.* (2002), pp. 70-1, 103-4.

technical compendia);the professionalisation of experts (making it easy to find people who had the relevant knowledge); a veritable explosion of universities and technical colleges combining research and teaching; the institutionalization of courier and mail services. To sum up: the knowledge revolution in the eighteenth century was not just the emergence of new knowledge; it was also better access to knowledge that made the difference, because the lower the access costs, the more knowledge is cumulative.[124]

Here is where the issues of education and ICT come into play. They can best be understood when incorporating them into the basic model of the knowledge economy's inner logic as described in this paper. Today's knowledge-based economy is still run by humans[125]; they need to understand the mechanisms at work, both formally and substantially, in order not only to further advance them, but to be able to manage prudently the powerful forces at work and give thoughtful direction to future development. Education plays the role of developing the considerable and ever-growing intellectual abilities and emotional capacities needed to meet these demands. Whereas education denotes the human factor of the knowledge-based economy, ICT stands for the pace and cost factor by raising the former and lowering the latter and, thereby, hugely increasing the dynamics of the mechanisms described.[126] If human agency is the engine of the knowledge-based economy's impressive machinery, ICT is best understood as its lubricant, whereas the interrelations discussed in

[124] Access to knowledge (A2K) is still vividly discussed as "the real basis for sustainable human development," e.g. in Yale's Information Society Project (see http://research.yale.edu/isp/a2k/wiki/index.php/Yale_A2K_Conference).

[125] They have to build knowledge out of mere information (see 1), they have to implement practical solutions (?) which grow out of the broad Ω-base and *vice versa*.

[126] ICT has not only lowered marginal access costs enormously (Müller, *op. cit.*, pp. 40, 41; Castells, *op. cit.*, pp. 34, 40, 41; Knoll, *op. cit.*, p. 2, it has opened the floodgates to even more rapid further technological progress, which has sometimes been called the third Industrial Revolution the paragon of which is the computer. Also, modern information technology has also produced new tools for conducting research, thus providing an immensely powerful positive feedback effect from prescriptive to propositional knowledge; Kurzweil, *op. cit.* (1999), pp. 44 *et seq.*, Mokyr, *op. cit.* (2002), pp. 79, 112, 113.

this paper could be viewed as the (physical/societal) laws to which its mechanisms adhere.

3.2 How to react. It is one thing to try to explain why we arrived at the situation in which we find ourselves today and to offer plausible explanations for it. It is quite another to think about how we should best react to and deal with these circumstances individually and socially.

With regard to the individual, which I have labelled the "human factor" of the knowledge-based economy, the most obvious consequence of living and working in such a society is the need for "lifelong learning". In order to take part and act successfully within the framework of a knowledge-driven and knowledge-dominated environment there seems to be no alternative but to be prepared to think creatively, basing one's thoughts on the enormous amount of knowledge already available. On the other hand, Kurzweil's[127] question "life in the twenty-first century – what remains of man?" takes on a special meaning against the background outlined in this paper: the individual has to struggle in order not to become a mere "*homo oeconomicus*" but to develop and cultivate values other than purely economic ones. Our humanistic virtues should not be completely subordinated to the economy and its rules. In Kant's famous words: forfeiting any aim, any thought, and any feeling to the economic demands of knowledge-driven efficiency would result in reversing "man's emergence from his self-incurred immaturity". In the end, then, only the "authority" may have changed, but man would still (or again) be unable to use his own understanding without the "guidance" of the "tyranny" of absolute and unconditional economic efficiency.

It is obvious that not only the individual, but also the key institutions of society have to adapt to the knowledge-based society. Etzkowitz and Leydesdorff coined the term "triple helix" of university-industry-government relations to denote the complexity of this task.[128] Much could

[127] Kurzweil, *op. cit.* The German title of his book "The Age of Spiritual Machines" "Homo Sapiens: Life in the 21st century – what remains of man?" poses this question primarily against the background of the computer revolution and the discussion about artificial intelligence.
[128] Etzkowitz *et al.*, *Introduction: Universities in the Global Knowledge Economy* (1997).

be said about the challenges each of these parts faces today against the background of a knowledge-based economy. Educational institutions will be considered only briefly. In order to enable individuals to function successfully as the "masters" of the mechanisms described in this paper, schools should try to impart to young people the ability to find their way in the jungle of facts available and to acquire special knowledge quickly. For this, students need to be taught basic knowledge on the contents, as well as methodological competence and the capability to acquire knowledge independently. The era of the school as a mere institution for drumming facts into the heads of pupils for a certain number of years has to be jettisoned. What is more, personal and social competence should be imparted, being as important a lubricant for today's economic machinery as is ICT.[129]

The universities, too, must consider their position in society in general and in the economy in particular. It is true that, due to the ever-faster creation of new knowledge, an "innovation gap"[130] has emerged which opens up between individual firms, attending to their short-term needs for product development, and to longer-term research, which is often located in university and government laboratories and has the potential to improve existing products incrementally, as well as to create future products and processes. The seeming disadvantage can turn out to be a strength which is vital to our society and our economy: from their position, universities may be better suited to warn against hazardous paths taken because of purely economic considerations i.e. to be a watchtower that keeps an eye on developments which are possibly dangerous in the long run but at the same time are vigorously pursued because of short-term economic benefits. In order to be able to serve as a sentinel or "cultural memory,"[131] however, they need some degree of financial and ideological independence from the economically and politically powerful. To endanger this independence by starving the universities financially or by weakening them through small-minded

[129] Wolff, *op. cit.*, pp. 258 *et seq.*; World Bank, *Education for the Knowledge Economy* (2004).
[130] Etzkowitz *et al.*, *op. cit.*, p. 2.
[131] Etzkowitz *et al.*, *op. cit.*, pp. 1, 3.

"party-politics" is a serious mistake with potentially disastrous long-term consequences.[132]

4. Conclusion

It was through the Industrial Enlightenment that the Scientific Revolution and the Enlightenment produced the Industrial Revolution and, finally, the knowledge-based economy as we know it today. Its inner dynamic produced an interaction of forces able to set free robust and self-sustaining economic growth powerful enough to overcome three strong negative feedback mechanisms which were operative throughout human history – Malthusian traps, diminishing marginal returns on investment, resulting in a hitherto inevitable slowdown and suffocation of economic growth over time, and negative institutional feedback mechanisms. The key driving factor of this pivotal paradigm shift is the double interaction between – what Mokyr called Ω-knowledge and ?-knowledge. Founded in what was the true achievement of the Scientific Revolution, a sound method overcoming dependence on mere chance for technological progress and acquisition of systematised knowledge, other revolutions could blossom, especially the Industrial Revolution(s) and, in its wake, the agricultural and military revolution. What is more, the game-theory Hawk-Dove-Model is a powerful tool for understanding better how especially the third-mentioned negative feedback mechanism could be overcome; in this paper it is applied within a historical setting for the first time.

[132] There should be no *ex ante* taboos, of course, and thinking about the former "social contract" (Etzkowitz *et al,* [1997], 1) between university and society. Many argue that now both long- and short-term contributions are possible, based on examples of firm formation (see the numerous examples of entrepreneurial spin-off start-ups; e.g. CAST – Center for Academic Spin-offs Tyrol - http://www.uibk.ac.at/ipoint/news/wirtschaft_und_wissenschaft/20021010.html - or the Yale Entrepreneurial Society - http://www.yes.yale.edu/show.php?page=about_yes_entrepreneur and research contracts. To a certain degree this surely is a desirable development, but only as long as it does not endanger the independence and "academic freedom" of the universities which are of crucial importance to the long-term well-being of a society. The basic question is how to design the social framework in order to set free the university system's potential contributions to a flourishing economy while at the same time not endangering their basic independence and autonomy.

The potential further benefits of future developments based on the knowledge-based economy seem auspicious. Economic progress and prosperity are important goals for individual and collective decision-making. It should not, however, be forgotten that this success story also contains the danger of economic reasoning becoming the sole motive for decisions whose consequences are not just of an economic nature but are much more far-reaching.[133] Although the economic evolutions of the last two and a half centuries were impressive and promising, they should not lead to a "one-dimensional"[134] reasoning becoming the new dogma of modern man. This would mean surrendering, in Kant's words, to just another "self-incurred immaturity".

REFERENCES

ADVISORY GROUP OF THE MINISTER FOR INFORMATION TECHNOLOGY OF NEW ZEALAND. 1999. The Knowledge Economy. *www.med.govt.nz/pbt/inforech/knowledge_economy.*

BARBER B., "Resistance by Scientists to Scientific Discovery", in Barber B. and Hirsch W. (eds), *The Sociology of Science*, (Macmillan: New York 1982), pp. 539-556.

BATESON G., *Geist und Natur: Eine notwendige Einheit*, (Suhrkamp: Frankfurt 1982).

BAUMOL W., *The Free-Market Innovation Machine: Analyzing the Growth Miracle of Capitalism*, (Princeton University Press: Princeton N.J 2002).

BELL D., *Die nach-industrielle Gesellschaft*, (Campus: Frankfurt 1973-75).

BRYSON B., *A Short History of Nearly Everything*, (Black Swan Books: London 2003).

CANTWELL J., "Japan's Industrial Competitiveness and the Technological Capabilities of the Leading Japanese Firms", in Arrison, T. S., Bergsten, C. F., Graham E. M. and Harris M.C (eds), *Japan's Growing Technological Capability: Implications for the US Economy*, (National Academy Press: Washington D.C. 1992), pp. 165-188.

[133] This issue is currently vividly debated in a number of sciences. One of the most telling discourses is that in jurisprudence where justice is replaced by efficiency as the guiding principle by proponents of the so-called "economic analysis of law."
[134] Compare Marcuse, *Der eindimensionale Mensch* (1964).

CARDWELL D.S.L., *Turning Points in Western Technology*, (Neale Watson Science History Publication: New York 1972).

CASTELLS M., 2001-2003. *Das Informationszeitalter*, 3 vols, (Leske + Budrich: Opladen 2001-03).

DE GREENE K.B., 'Will There Be a Fifth Kondratiev Cycle/Structure?', *Systems Research* 10 (1993), pp. 41-56.

DELIUS C., GATZEMEIER M., SERTCAN D. AND WÜNSCHER K., *Geschichte der Philosophie von der Antike bis heute*, (Könemann: Cologne 2000).

ECO U., *Einführung in die Semiotik*, (UTB: Munich 1972).

ENCYCLOPEDIA BRITANNICA. 2001. DVD edition.

ENTERWEB. 2004. Knowledge Economy. *www.enterweb.org/know.htm*.

ETZKOWITZ H., "The Entrepreneurial University and the Emergence of Democratic Corporatism", in *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*, (Pinter: London 1997), pp. 141-154.

ETZKOWITZ H. and LEYDESDORFF L., "Introduction: Universities in the Global Knowledge Economy" in *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*, (Pinter: London 1997), pp. 1-10.

FISCHER E.P., *Aristoteles, Einstein & Co.: Eine kleine Geschichte der Wissenschaft in Porträts*, (Piper: Munich 2000).

————, *Die andere Bildung: Was man von den Naturwissenschaften wissen sollte*, (Ullstein: Ulm 2003).

FISCHER K., "Die neue Ordnung des Wissens: Experiment – Erfahrung – Beweis – Theorie" in van Dülmen, R. and Rauschenbach (eds), *Macht des Wissens: Die Entstehung der modernen Wissensgesellschaft*, (Böhlau: Cologne 2004), pp.155-186.

GODDARD J., "Editor's Preface", in Hepworth Mark, *Geography of the Information Economy*, (Belhaven Press: London 1989), pp. xiv-xvii.

HAWKING S., *Die illustrierte kurze Geschichte der Zeit*, (Rowohlt: Hamburg 1988-1997).

————, *Das Universum in der Nußschale*, (Hoffmann und Campe: Hamburg 2002).

HAYEK F.A., *Law, Legislation, and Liberty*, (University of Chicago Press: Chicago 1973-76).

HEPWORTH M., *Geography of the Information Economy*, (Belhaven Press: London 1989).

HÖFFE O., *Kleine Geschichte der Philosophie*, (Beck: Munich 2001).

JAY P., *Road to Riches or The Wealth of Man*, (Phoenix: London 2000).

JUNKER R. and SCHERER S., *Evolution: Ein kritisches Lehrbuch*, 5th edition, (Weyel: Giessen 2001).

KANT I. 1784. *An Answer to the Question: "What is Enlightenment?"*, to read under ethics.acusd.edu/Books/Kant/Enlightenment/what-is-enlightenment Kant.htm.

KENNETH N.P., *Game Theory and Evolutionarily Stable Strategies*, College of the Holy Cross. *www.maths.bris.ac.uk/research/stats/Postgrad/topics/col_mc_2.html* (1999).

KNOBLOCH E., "Copernicanische Wende: Signatur des Jahrhunderts" in van Dülmen, R. and Rauschenbach, S. (eds), *Macht des Wissens: Die Entstehung der modernen Wissensgesellschaft*, (Böhlau: Cologne 2004), pp. 89-110.

KNOLL N., *Progress towards the Knowledge-Based Economy*, WIFO Working Papers 161/2001, (Österreichisches Institut für Wirtschaftsforschung: Vienna 2001)

KRANAKIS E., "Hybrid Careers and the Interaction of Science and Technology", in Kroes, P. and Bakker, M. (eds), *Technological Development and Science in the Industrial Age*, (Kluwer: Dordrecht 1992), pp. 177-204.

KRUSELL P. and RIOS-RULL J.-V., 'Vested interests in a Positive Theory of Stagnation and Growth', *Review of Economic Studies* 63 (2), 1996, pp. 301-329.

KUHN T., *The Structure of Scientific Revolutions*, (University of Chicago Press: Chicago 1962).

KURZWEIL R., *Homo Sapiens: Leben im 21. Jahrhundert – Was bleibt vom Menschen?*, (Kiepenheuer & Witsch: Cologne 1999).

KUZNETS S., *Economic Growth and Structure*, (W.W. Norton: New York 1965).

LANDES D., *The Wealth and Poverty of Nations: Why are Some so Rich and Some so Poor?*, (W.W. Norton: New York 1998).

LIVI-BACCI M., *A Concise History of World Population*, (Blackwell: Oxford 1997).

LUNDVALL B., 'Information Technology in the Learning Economy: Challenges for Development Strategies', *Communications & Strategies* 28 (4), 1997, pp. 177-191.

MALCHUP F., *Knowledge: Its Creation, Distribution and Economic Significance*, 3 Vols., (Princeton University Press: Princeton N.J. 1980-84).

MANKIW N.G., *Principles of Economics*, 2nd edition, (Harcourt: Orlando 2001).

MARCUSE H., *Der Eindimenstionale Mensch – Studien zur Ideologie der fortgeschrittenen Industriegesellschaft*, (Neuwied: Berlin 1969).

MCGOVERN P., *Information Wealth*, (Two Ten Communications: Reuters, 20 November 1998).

MOKYR J., *The Lever of Riches: Technological Creativity and Economic Progress*, (Oxford University Press, Oxford 1990).

———, 'Cardwell's Law and the Political Economy of Technological Progress', in *Research Policy* 23 (5), 1994, pp. 561-574.

———, *The Gifts of Athena: Historical Origins of the Knowledge Economy*, (Princeton University Press: Princeton N.J. 2002).

MOWERY, D.C. and ROSENBERG N., *Paths of Innovation: Technological Change in Twentieh-Century America*, (Cambridge University Press: Cambridge 1998).

MÜLLER W., "Fallen wir durchs Netz? Herausforderungen und Chancen für die Wirtschaftspolitik in der Wissensgesellschaft", in Verein der Freiburger Wirtschaftswissenschaftler (ed.), *WissensWert?: Ökonomische Perspektiven der Wissensgesellschaft, 3. Freiburger Wirtschaftssymposium*, (Nomos: Baden-Baden 2000), pp. 39-50.

NOLL J. and BRÄNDLE U., *Mosaisches Recht im Licht moderner Ökonomie*, (Verlag Österreich: Vienna 2004).

OECD, *The Knowledge Economy: Science, Technology and Industry Outlook*, (OECD: Paris 1996).

OECD, *Communications Outlook 2001*, (OECD: Paris 2001).

O'GORMAN R., *Game Theory*, (Northwestern University 2003). *http://ccl.northwestern.edu/netlogo/models/community/GameTheory*.

OLIVER M., *Die Geschichte der Philosophie: grosse Denker gestern und heute*, (Bechtermünz: Munich 1998).

PAJARES F., *The Structure of Scientific Revolutions*, (Emory University, Division of Educational Studies 2004). *http://www.emory.edu/EDUCATION/mfp/kuhnsyn.html*.

PATZELT W.J., *Einführung in die Politikwissenschaft: Grundriss des Faches und studiumbegleitende Orientierung*, (Wissenschaftsverlag Richard Rothe: Passau 1997).

POPPER K.R., *The Logic of Scientific Discovery*, (Hutchinson: London 1934).

———, *Conjectures and Refutations: The Growth of Scientific Knowledge*, (Routledge & Keagan Paul: London 1963).

PICOT A. and FIEDLER M., "Der ökonomische Wert des Wissens" in Verein der Freiburger Wirtschaftswissenschaftler (ed.), *WissensWert?: Ökonomische Perspektiven der Wissensgesellschaft, 3. Freiburger Wirtschaftssymposium*, (Nomos: Baden-Baden 2000), pp. 15-38.

PRESTWICH K.N., *Game Theory and Evolutionary Stable Strategies*, (College of the Holy Cross, Department of Biology). *www.holycross.edu/departments/biology/kprestwi/behavior/ESS/HvD_intro.html#intro* (1999).

ROMER, P.M., 'Increasing Returns and Long-run Growth', in *Journal of Political Economy*, University of Chicago Press, 94 (1986), pp. 1002-37.

———, 'Endogenous Technological Change', in *Journal of Political Economy*, University of Chicago Press, 98 (1990), pp. 71-102.

Russel, B., *Philosophie des Abendlandes*, (Europaverlag: Vienna 1945-1997).

Sagan, C., *Unser Kosmos: Eine Reise durch das Weltall*, (Bechtermünz Verlag: Augsburg 1980-97).

Seiffert H., *Einführung in die Wissenschaftstheorie 1: Sprachanalyse, Deduktion, Induktion in Natur- und Sozialwissenschaften* (12th edition), (Beck: Munich 1996).

Shapiro C. and Varian H.R., *Information Rules: A Strategic Guide to the Network Economy*, (Harvard Business School Press: Boston 1999).

Skyrme D.J., *The Global Knowledge Economy and its implication for markets*, 1997. *www.skyrme.com/insights/21gke.thm*.

Smith J. M., *Evolution and the Theory of Games*, (Cambridge University Press: 1982)

Tignor R, Adelman J, Aron S, Kotkin S, Marchand S, Prakash G, and Tsin M., *Worlds Together, Worlds Apart: A History of the Modern World from the Mongol Empire to the Present*, (W. W. Norton: New York and London 2002).

Tversky, A. and Kahneman D., 'Rational Choice and the Framing of Decisions', *Journal of Business* (1986).

United Kingdom Department of Trade and Industry (Secretary of State for Trade and Industry), *Our Competitive Future: Building the Knowledge Economy*, (United Kingdom Department of Trade and Industry: London 1998).

Wahren, "Wissensmanagement" und "Lernende Organisation", Zwei Seiten einer Medaille, in Verein der Freiburger Wirtschaftswissenschaftler (ed.), *WissensWert?: Ökonomische Perspektiven der Wissensgesellschaft, 3. Freiburger Wirtschaftssymposium*, (Nomos: Baden-Baden 2000), pp. 279-286.

Weigel W., "Zur Rolle der Information in der Wirtschaft", Dosoudil Ilse (ed.), *Information und Wirtschaft: Aspekte einer komplexen Beziehung*, (Facultas: Vienna 2003), pp. 11-24.

Weischedel W., *Die philosophische Hintertreppe: die grossen Philosophen in Alltag und Denken*, (DTV: Munich 1975-97).

Weitzmann M., 'Hybridizing Growth Theory', *American Economic Review of Books*, 48 (9), 1996, pp. 47-50.

Wolff H., "Auf dem Weg zur Wissensgesellschaft. Ergebnisse und Folgerungen aus den Delphi-Studien" in Verein der Freiburger Wirtschaftswissenschaftler (ed.), *WissensWert!?: Ökonomische Perspektiven der Wissensgesellschaft, 3. Freiburger Wirtschaftssymposium*, (Nomos: Baden-Baden 2000), pp. 253-264.

World Bank, *World Development Report 1999/2000*, (World Bank: Washington 2000).

World Bank. 2004. Education for the Knowledge Economy. *www1.worldbank.org/education/eke.asp*.

Zimmer R., *Das Philosophenportal: Ein Schlüssel zu klassischen Werken*, (DTV: Munich 2004).