Technology Push, Demand Pull And The Shaping Of Technological Paradigms - Patterns In The Development Of Computing Technology

Jan van den Ende & Wilfred Dolfsma

ERIM REPORT SERIES *RESEARCH IN MANAGEMENT*	
ERIM Report Series reference number	ERS-2002-93-ORG
Publication	October 2002
Number of pages	26
Email address corresponding author	j.ende@fbk.eur.nl, w.dolfsma@fbk.eur.nl
Address	Erasmus Research Institute of Management (ERIM) Rotterdam School of Management / Faculteit Bedrijfskunde Erasmus Universiteit Rotterdam P.O.Box 1738 3000 DR Rotterdam, The Netherlands Phone: +31 10 408 1182 Fax: +31 10 408 9640 Email: info@erim.eur.nl Internet: www.erim.eur.nl

Bibliographic data and classifications of all the ERIM reports are also available on the ERIM website:
www.erim.eur.nl

ERASMUS RESEARCH INSTITUTE OF MANAGEMENT

REPORT SERIES
RESEARCH IN MANAGEMENT

BIBLIOGRAPHIC DATA AND CLASSIFICATIONS		
Abstract	An assumption generally subscribed in evolutionary economics is that new technological paradigms arise from advances is science and developments in technological knowledge. Demand only influences the selection among competing paradigms, and the course the paradigm after its inception. In this paper we argue that this view needs to be adapted. We demonstrate that in the history of computing technology in the 20th century a distinction can be made between periods in which either demand or knowledge development was the dominant enabler of innovation. In the demand enabled periods new technological (sub-) paradigms in computing technology have emerged as well.	
Library of Congress Classification (LCC)	5001-6182	Business
	5546-5548.6	Office Organization and Management
	HD 45	Technological innovations
Journal of Economic Literature (JEL)	M	Business Administration and Business Economics
	M 10 L 2	Business Administration: general Firm Objectives, Organization and Behaviour
	L 96 O 33	Telecommunications Technological Change: Choices and Consequences
European Business Schools Library Group (EBSLG)	85 A	Business General
	100B 240 B	Organization Theory (general) Information Systems Management
	15 A	Technological innovation
Gemeenschappelijke Onderwerpsontsluiting (GOO)		
Classification GOO	85.00	Bedrijfskunde, Organisatiekunde: algemeen
	85.05 85.08	Management organisatie: algemeen Organisatiesociologie, organisatiepsychologie
	85.15	Onderzoek en ontwikkeling
Keywords GOO	Bedrijfskunde / Bedrijfseconomie	
	Organisatieleer, informatietechnologie, prestatiebeoordeling	
	Technologische vernieuwing, vraag en aanbod, computerwetenschap	
Free keywords	Enablers of innovation, technological paradigms, history of computing	

Technology push, demand pull and the shaping of technological paradigms - Patterns in the development of computing technology

Jan van den Ende[1] & Wilfred Dolfsma[2]

Abstract

An assumption generally subscribed in evolutionary economics is that new technological paradigms arise from advances is science and developments in technological knowledge. Demand only influences the selection among competing paradigms, and the course the paradigm after its inception. In this paper we argue that this view needs to be adapted. We demonstrate that in the history of computing technology in the 20th century a distinction can be made between periods in which either demand or knowledge development was the dominant enabler of innovation. In the demand enabled periods new technological (sub-) paradigms in computing technology have emerged as well.

Keywords: enablers of innovation, technological paradigms, history of computing.

JEL Codes: L96 – Telecommunications
O33 - Technological Change: Choices and Consequences

[1] Jan van den Ende is Associate Professor Management of Technology and Innovation, at the Rotterdam School of Management, Erasmus University Rotterdam. Adress: Rotterdam School of Management, Room F2-67, P.O. Box 1738, 3000 DR Rotterdam, Tel. +31-10-4082299, Fax +31-10-4089014, email J.Ende@fbk.eur.nl.

[2] Wilfred Dolfsma is Assistant Professor at Rotterdam School of Management (same address), and Associate Professor at Maastricht University; W.Dolfsma@fbk.eur.nl

Technology push, demand pull and the shaping of technological paradigms - Patterns in the development of computing technology

1 Introduction

An important matter in understanding the development of technologies is what effects push and pull factors play, supply and demand. The field of technology studies, in the 1970s, finally came to the conclusion that both were important for innovation and the development of technologies (Dosi, 1982; Mowery & Rosenberg, 1979). The debate stimulated the development of new sociological and economic approaches, in which technological development was conceived of as an interaction process between societal, economic, political and technological factors, the influence of which could not easily be distinguished from each other (Bijker et al., 1987; Bijker & Law, 1992). The unsettling aspect about this conclusion is that it easily gives rise to the thought that anything might happen, that no regularities could be found. Such a conclusion could amount to science forfeiting its role in society. Many historians of technology as well as historians in general are 'splitters' in the sense that they seek to make very detailed accounts of history and believe that more general perspectives are impossible.[3] There is, however, a need for a scientific approach in the history of technology that tries to 'lump' brute facts together and seek to find more general patterns.

In the literature the concepts of demand pull and technology push either referred to the sources of innovation or to the motivations for innovators (Coombs et al., 1987; Mowery & Rosenberg, 1979; Rothwell, 1992; Schmookler, 1966). In this paper we investigate the influence of technology and knowledge factors or market factors as enablers of innovation, particularly for innovation in computing technology. Technology factors refer to the speed and direction of technological knowledge. Changes in state-of-the-art of technological knowledge may create important conditions for the development of new or improved products. Market factors point to the rise or existence of a manifest or potential market for a product. We use the term 'enabler' and not the more common term 'driver' to stress the point that demand or knowledge as contextual

[3] The distinction in the approach of historians between 'lumpers' and 'splitters' is from *the Economist* (September 5, 2000 "Big-picture history").

factors alone cannot generate change, but that actors are needed who create the innovations based on this knowledge or directed to this demand. Moreover, although more enabling factors are possibly important as conditions for innovation, such as an innovative culture in a firm and government support, we focus on demand and technological knowledge as these play the most important role in the long term, and as such an analysis facilitates comparisons between different fields of technology. We demonstrate, contrary to what is generally believed in evolutionary economics, that periods and fields of technology exist in which either technological knowledge development *or* the changes in the market were most important as enablers of innovation. Moreover, in contrast to most of the literature in evolutionary economics, we demonstrate that the emergence of new technological paradigms can be enabled by demand, whereas the further course and direction of development can be enabled by knowledge development. Statements on the enablers of innovation can be mace only if they relate to specific periods and fields of technology. This 'time-and-technology-specificity' distinguishes the approach in this paper from the positions in the early push versus pull discussion in technology studies.[4] As such, we are in between the lumpers and the splitters on the issue of the history of computing technology.

2 Evolutionary economics on the development of technology

Evolutionary economy makes a distinction between technical/knowledge and market influences on technologies. They consider technological developments to be ordered into technological paradigms or technological regimes.[5] A technological paradigm refers to the core knowledge base involved in a specific field of technology and to common aspects of the problem solving activities of engineers in that field (Dosi, 1982, 1988; Dosi et al., 1993). The development along the lines of the paradigm is often defined as a technological trajectory.[6] The original meaning of the concept technological regime refers to the basic design features of a specific product and to the

---

[4] Also in the history of technology attempts have been made to generate generic answers to the question of push and pull. See for instance Smith and Marx (1994).

[5] The concept of technological paradigm is coined in G. Dosi (1988); the concept of technological regime in Nelson & Winter (1982).

[6] A 'technological paradigm' defines contextually the needs to be fulfilled, the scientific principles and the material technology to be used. In other words, a technological paradigm can be defined as a 'pattern for solution of selected techno-economic problems based on highly selected principles derived from the natural sciences. A technological paradigm is both a set of *exemplars* (…) and a set of *heuristics* **…' '***A technological trajectory* (…) is the activity of technological progress along the economic and technological trade-offs defined by a paradigm'. Dosi (1988, p. 224, italics in original).

technological framework engineers in the field use explicitly or implicitly that shape of their activities.[7]

In evolutionary economics scientific advances are thought to create new paradigms, whereas market demand determines the selection between different paradigms and the trajectory of the selected one(s). The development of scientific or technological knowledge is considered to be the major if not the sole factor determining changes of paradigms or regimes. The authors of OECD (1992) speak of a 'new technological paradigm emerging from the techno-scientific breeding ground' (OECD, 1992, p.39). Demand only exerts influence *within* the boundaries of paradigms. For instance Dosi notes about 'changing demand conditions':

> '(…) these factors are likely to be fundamental ones, influencing both the rate and direction of technical progress, but *within the boundaries* defined by the nature of technological paradigms.' (Dosi, 1988, p.227)

> '(…) environment-related factors (such as demand, relative prices, etc.) are instrumental in shaping (a) the rates of technical progress; (b) the precise trajectory of advance, within the (limited) set allowed by any given 'paradigm'; and (c) the selection criteria amongst new potential technological paradigms. However, each body of knowledge, expertise, selected physical and chemical principles, etc. (that is, each paradigm) determines both the opportunities of technical progress and the boundaries within which 'inducement effects' can be exerted by the environment. Moreover, the source of entirely new paradigms is increasingly coming from fundamental advances in science and in the (related) 'general' technologies (e.g. electricity, information-processing, etc.).' (Dosi, 1988, p. 228)[8]

According to Dosi, his position can 'help resolve the long debate in the literature about the relative importance of 'demand pull' versus 'technology push' (Dosi, 1988, p. 228). A believe

[7] The concept of technological regime has also been used broader, referring to the characteristics of innovation processes in specific industrial sectors (Malerba & Orsenigo, 1997), and to formal and informal rules sets underlying innovation processes in specific products (Rip & Kemp, 1998). See also: Georghiou et al. (1986), Kemp (1994), Nelson & Winter (1982) and van den Ende & Kemp (1999).

[8] Dosi does remark that the speed of and way in which an innovation is generated depends on the specific sector and time involved. This would depend, a.o., on the opportunities for innovation that each paradigm leaves (Dosi, 1988, p. 229).

that the dynamics of technological knowledge is mostly autonomous is founded on the idea that physical factors predominate in the course technological knowledge takes. Molino (1999) speaks for instance of the 'intrinsic dynamics' of technology, exemplified by the relation system-component. Physical factors can certainly set boundaries for or hinder the development of technological knowledge by closing off specific paths of development, or by raising problems that limit the speed of development. On the other hand, promising directions of development may present themselves, as is shown by nature, thus stimulating the development in a specific direction and facilitating a higher speed of development (Vincenti, 1994). The effects of physical factors differ across fields and periods, a fact noted by evolutionary economists as well (Malerba & Orsenigo, 1997, p. 94; Dosi, 1988). We share with evolutionary economics the attention for the influence of technological knowledge and demand on the development of technology. However, we put into question the sequence postulated in evolutionary economics concerning their influence during the different phases of development of a technological paradigm. In order to make our case, we present an analysis in some detail of the development of computing technology, a technology that has had a profound impact on our economy and society.

Methodology

Determine the relative influence of technological knowledge or demand on the development and diffusion of technology in a specific field and period then becomes the crucial issue. We draw on Dosi (1988) who evaluates and tries to understand if a technology would have been adopted in a previous era given the respective demand conditions ('relative prices'). In case a technology would have been adopted under the conditions existing previously, he concludes that the new technology must be superior to the old ones:

> '[I]nnovation yields new techniques which are likely to be superior to the old ones irrespective of relative prices, either immediately, as often is the case of many microelectronics-based processes (…), or after a learning period (…). If the new techniques had existed before they would also have been adopted at the 'old' relative prices.' (Dosi, 1988, p.227).

In fact Dosi here describes a situation that we would characterize as technology-enabled. We follow Dosi in making such counterfactual comparisons over time in a specific field of technology. If an innovation is adopted at a specific moment in time, the question is whether users would in all likelihood have adopted the same innovation earlier at the relative prices prevailing at that time. If users would then already have adopted the innovation, apparently (latent) demand already existed, and hence technological change explains the adoption later on. Changing demand at least partly explains the development of a technology under study.[9] In fact, this is an approach very much in line with Schumpeter's (1943, chapter 17) dynamic welfare perspective.

Tidd et al. (2001, p.164), for instance, find that latent demand is of great importance to understand the development of technology. A closer study of the activities of (potential) users may further clarify if indeed changes in their situation, in their activities, or changes in the cost of production factors (particularly for process technology) are reasons for not adopting a technology even if it had existed. The nature of the counterfactual argument that we develop requires a closer look at the users from a specific era than Aversi et al. (1999) adopt in their study of the effects of demand on the development of technology. We believe that, while simulations and other such techniques are important, they cannot substitute for empirical research. A look at the users that is only casual would not stand the test of the criteria that Mowery and Rosenberg (1979) propose. The volume and type of their activities can indicate if the technology would have rendered advantage and thus if the user would have adopted it.

Our definition of demand differs from the one that prevailed in the push-pull debate of the 1970s in the field of technology studies. In that debate, the motivation of innovators were referred to, while we refer to the users of a technology (cf. Mowery & Rosenberg, 1979; Coombs et al., 1987). Growing demand may of course be a motivating factor for innovators, but would then not be primary or unmediated.

Technological knowledge and demand factors as defined in this paper of course interact: technological possibilities for instance may become clear with specific demands in sight, and demand may develop because technological possibilities emerge. But both technology and demand also have an important dynamics of their own, which makes it important in a study to distinguish them.

The procedure we adopt is similar to the approach in so-called 'technology measurement'-studies of the 1980s (Alexander & Mitchell, 1985; Saviotti, 1985; Saviotti et al.,

---

[9] Final consumers are different from firms who chose to acquire a product, even if it is the same product. Although the decision-making processes of firms are mostly more rational, the perceived rationality of decision making processes in firms should not be overestimated. Nevertheless, the lapse of time between a decision to invest or act and the actual behavior is longer for firms than for consumers, and so decisions in firms may be thought to be more rational. This does not mean, however, that our method used would be useless for consumer goods.

1982). The objective there was to determine the rate of progress made in specific fields of technologies. Improvement of a technology was measured by means of certain performance characteristics. The weighted sum of these advances, relative to the estimated values attached to these characteristics for consumers, was determined. These authors and others based their estimates on the prices and performance of the supply, not on data on the actual users. The results were independent of specific consumer groups and were considered to indicate the rate of technological progress. In contrast to the 'technology measurement' approach, we study real changes in the situation of users instead of estimates of users' preferences. In doing so, the analysis in this paper conforms with the requirement of Mowery and Rosenberg (1979, p. 141) that 'a shift in demand curve must be shown to have occurred', since changes in the volume and type of activities of (potential) users generate such shifts. Most of the studies that were criticized by Mowery and Rosenberg focused on actions and motivations of innovators as indicators of demand.

In line with the general approach in evolutionary economics, technological factors of import are the speed and direction of technological knowledge development in a specific field. Both can vary. Technological knowledge may give rise to the emergence of a radically new technology forming the origin of a new technological paradigm. Technological knowledge may also facilitate the improvement of existing products or make their production less costly, or both. In these cases the development of technological knowledge becomes evident in price-performance improvements in new products compared to existing ones. Performance may refer to 'basic' performance parameters, such as speed and memory capacity of computers, or in, often related, performance characteristics that are actually evaluated by users, such as user friendliness. It is, however, within a technological paradigm that price-performance measures make most sense. Several authors have indicated that particularly in the first period after the introduction of a completely new product that learning effects generate price-performance improvements (Arthur, 1988; Sahal, 1981). We are concerned with profound and sustained improvements in the price-performance ratios of a technology.

3 Computing technology

Until well into the 1980s an internalist stance prevailed in the literature on the history of computing technology, focusing on inventions and the people that made them, explaining the growth of the field with reference to developments in the relevant knowledge base. Given the diversity of the technological field of computing technology (see Figure 1), not only including digital, electrical devices, such a view seems limited already at first glance. Demand factors were often restricted to the role of the military in the development of early computers (Goldstine, 1972;

Mahoney, 1988; Metropolis et al., 1980; Nijholt & van den Ende, 1994; Williams, 1985).[10] More recent literature pays more attention to the history of the computer industry and to the wider social contexts of the applications of computing technology (Campbell-Kelly & Aspray, 1996; Ceruzzi, 1998). These authors rarely distinguish explicitly between the different forces in the development of the field. Beniger (1986) is an exception is, emphasizing the societal background of the emergence of the computer revolution. According to him, the emergence of computing technology in the twentieth century has to be explained with reference to a general control crisis, emerging in the nineteenth century in Western societies, and continuing during the 20th century. In his eyes the growing speed and complexity of the material processing systems (encompassing production, distribution and sales systems) caused the control crisis. Beniger's analysis is interesting as he also considered societal changes on the development of computing technology. However, he in fact takes a social determinist stance, leaving out of his account the autonomous improvements of computing technology. Below we will demonstrate that Beniger's stance is accurate for the 1900-1960 period. After 1960 technology knowledge development in the field of computing technology become far more important. As we will see, it concerned different types of knowledge development before and after 1990.

[10] The attention is mostly focused on the role of the military in stimulating computing technology (see Goldstine (1972) and Metropolis et al. (1980)); this may be due in part to these authors' involvement in military projects that contributed to the development of the digital computer.

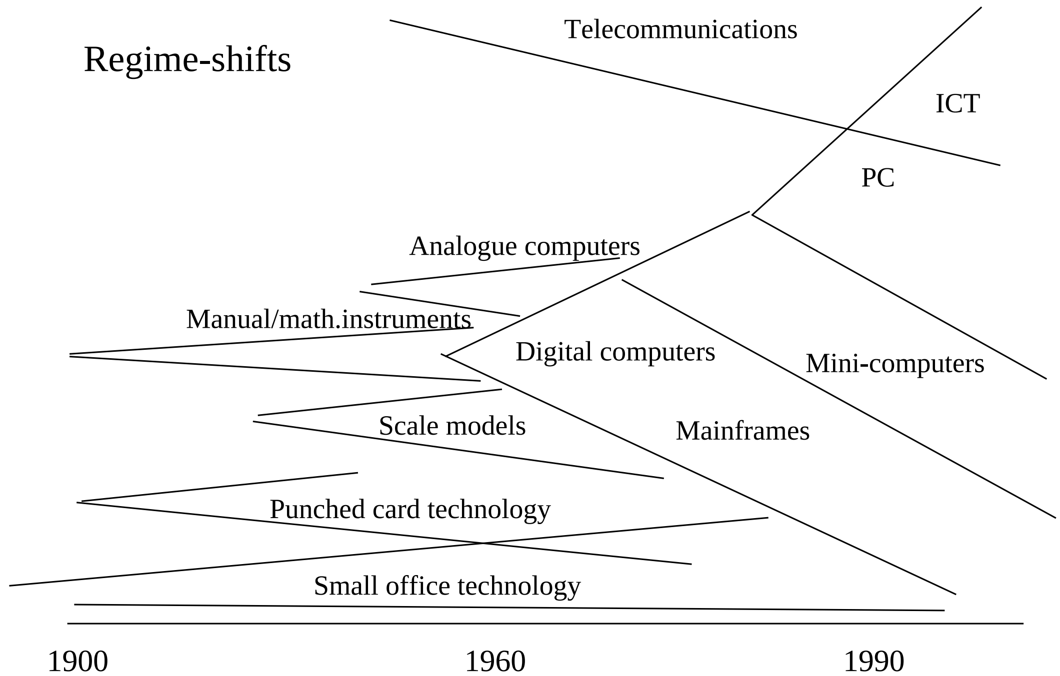

Figure 1: Paradigms in computing technology.

Source: Van den Ende and Kemp (1999)

Freeman and Perez (1988) define a techno-economic paradigm as affecting broad sectors of the economy and society, and thus the concept refers to a broader phenomenon than the concept of technological paradigm. They consider techno-economic paradigms central in the emergence of long waves in the economy, and argue that microelectronics and computers are central to the present wave (Freeman, 1997; Freeman & Perez, 1988). This paper demonstrates that technological factors were paramount in the development of microelectronics and computers in the period after 1960; before that year demand factors dominated. Defying chronology, we start with the last period, as it will be the one that is best preserved in our readers' mind. The second period (1960-1990) is a period that corroborates the evolutionary economic theory of technological development. For that reason, the third period is both the most interesting as well as the one on which evidence is most erratic. We leave that one for last.

Connectivity in the 1990s

We begin our overview of the history of computing in the most recent period, the period from about 1990 to the present. In that period the convergence of two types of technology, computing and telecommunications technology, was central. In a short period of time the use of computers for communication purposes, particularly by means of email and Internet, became popular. Most explanations for this development point to the availability of internet technology for a larger public due to the end of the cold war, and increasing overall demand for communication (Abbate 1999). These explanations underestimate the influence of development of technological knowledge as an enabler for the convergence of the two types of technologies. The increasing digitization of telecommunications technology and rapid development of knowledge of the physical connectivity of telecommunication and computer technology were preconditions for the convergence of the two kinds of technologies. Several types of new knowledge were developed for this purpose already at the end of the 1960s and in the 1970s, such as packet switching, layering and routing (Abbate, 1999, pp. 56-64 and 114-130; Moschovitis et al., 1999). The end of the cold war allowed for what Levinthal (1998) calls ‘speciation’ – the introduction of existing technological knowledge in a new environment where it can be put to good use and where resources are available more abundantly. Moreover in the 1990s computer scientists developed browsers and the World Wide Web (Abbate, 1999, pp. 212-216). These types of knowledge were required for the connectivity of computing technology and communications technologies, and for the rise of the Internet.

Another factor is needed to explain the rapid adoption and diffusion in the 1990s of Internet technology. The local area networks that many organizations established in this period were often not primarily meant for external communication purposes, but instead had to facilitate the implementation of new versions of user software within the organization. Now new software programs had to be installed only once on the local server, instead of on each individual desktop computer in the organization. These local area networks were an essential precondition for the subsequent success of Internet and other computer-based communication systems. In fact, these local area networks generated scale effects in the maintenance of internal computer infrastructures of organizations and their communication systems.

While the post 1990 era does not offer a clear story of developments in technological knowledge being the only enabler of developments in computing technology, it is clear that rising demand cannot explain the convergence of computing and communication technologies. If the new technologies would have been offered before, it is most likely that they would have been adopted then. The demand for computer supported communication that became manifest in the post 1990 period already existed. Therefore technological factors, developments in the knowledge about connecting computing and telecommunications technologies, specified above, and the complementary use of an existing infrastructure, were important enablers for the development of computing technology, making possible its new and warmly welcomed communication applications. Although for this third period as well as for the second period – to be discussed immediately below – developments in technological knowledge are the enablers, the nature of the technological knowledge involved was different before 1990, when advances in microelectronics, leading to improved price-performance ratios of stand alone computers, were the most important enablers. After 1990 it becomes increasingly difficult to make overall measurements of these ratios, since new types of computers (notebooks, PDAs) were introduced. According to some, for instance Jorgenson & Stiroh (2000, p. 127), the price-performance indicators still improved markedly as compared to the period between 1960 and 1990, from 20% up to 28% between 1995 and 1998. Others indicate that prices of computing technology stabilised at the end of the 1990s (CBS, 2002). Even if it is true that price performance indicators accelerated after 1990, this was caused by different developments than the increases in price-performance measures before 1990.

Origin and development of digital computers

The second period, from 1960 to 1990, is the period of the development but most importantly the impressive diffusion of electronic digital computers. In the 1950s digital computers were still expensive, bulky machines, prone to failure and in most applications offering only limited advantages compared to other existing technologies. After about 1960 these digital computers started to improve rapidly. Digital computing technology significantly improved on many performance characteristics, such as speed, memory capacity, size and reliability, while at the same time the price decreased drastically. The manufacturers of computers, moreover, used part of the speed and memory performance of computers to improve the user friendliness of the software. This process started in 1960, when manufacturers brought transistorized, second generation, digital computers on the market (Ceruzzi 1998, pp. 65-77). It continued for decades, as chip technology, initially memory chips, and later on the microprocessor, appeared on the market, leading to third-generations computers. Transistors and chip technology were essential for the introduction of new types of computers, particularly minicomputers and personal computers (Langlois, 1992). Regression analysis demonstrates that the price-performance ratio of different types of computers improved by a factor of about 20% a year between 1951 and 1984, taking speed and memory capacity as main indicators of performance (Gordon, 1989).[11] After 1984 the process of sustained improvement in price-performance measures continued. The extent and duration of these price-performance improvements may well be unprecedented in the history of technology since no examples can be found in the literature that equals this technological development.[12]

It is clear that the development of fundamental technological knowledge, particularly in the field of solid-state physics and microelectronics, were important in the development of the digital computer in this period. The development of scientific and technological knowledge was highly rewarding as a resource for improvement of products such as chips and computers. Although traditional learning effects, such as better organization of design and production and improved distribution channels have certainly added to the improved price-performance ratio of the digital computer, the development of fundamental technological knowledge stands out. The trajectory started by solid state physics provided physicists and engineers for enormous possibilities for advancing computing technology (Braun and MacDonald, 1978; Queisser, 1988). The improved and cheaper second-generation digital computers found applications, particularly in data processing, that would not have justified the application of the more expensive and lower performing first generation computers. This certainly applied to the minicomputers and third generation computers, introduced in the 1960s (Ceruzzi, 1998, pp. 182-191). Had digital computers with these prices and performance been available before, they would have undoubtedly been used earlier, even before the 1950s.

Compared with previous times, developments in technology and technological knowledge now resulted in far greater societal impacts. The availability of improved and cheaper computing technology, based on microelectronics, formed an important impetus for organizations to computerize all kinds of data processing and computing activities, including the development of computer-based management information systems. The scope and scale of the activities of organizations were often changed in turn (Venkatraman, 1991). The sheer number of computers applied increased far more rapidly than in previous periods. In many applications the digital

[11] Although the price of first generation digital computers already started to decrease in the late 1950s, we take the first practical application of second generation computers around 1960 as a starting point for the period where development of computing technology was knowledge-enabled. The reason is that new product knowledge, and particularly knowledge in the field of micro-electronics, caused price-performance ratios to increase for second-generation machines, whereas the improvements of first generation computers in the 1950s were mainly due to 'traditional' learning effects.

[12] See Alexander and Mitchell (1985); Knight (1985); Saviotti (1985); Saviotti et al. (1982).

computer substituted other computing technologies, but many new applications emerged as well. Rapidly developing computing technology became an enabling force behind changes in management (Scott Morton, 1991). Furthermore, in communication, media (De Sola Pool, 1990) and the financial sector (Colton & Kraemer, 1980; Michie, 1999; Nightingale & Pool, 2000) the computer stimulated or facilitated important changes.

For the different digital computer paradigms in this period the view that technological knowledge enables developments in technology mostly holds. Technological knowledge, particularly knowledge of microelectronics, was an enabling force behind the emergence of new technology, particularly mini-computers and personal computers. Fundamental technological knowledge was the primary enabler of the improvements and diffusion of mainframe computers, minicomputers and personal computers. Latent demand for these computers already existed as will also become clear in the next section, and so demand factors play a relatively minor role in the diffusion of these technologies.

Growing demand (1900-1960)

During the period from 1900 to 1960, demand was far more important for the emergence and spread of new computing technologies than in the other period discussed. We show this by discussing two cases of typical computing practices.

In the period 1900-1960 the field of computing technology included three different types of activities: data processing, technical and scientific computing, and computing for process control, mainly in industry. Different people performed these activities for different purposes, and they applied different computing technologies. Technologies applied in the field of data processing were desk calculating machines and punch card machines. Engineers and scientists applied slide rules, graphical aids and analogue computing machines for technical and scientific computing activities. Electrical and mechanical control devices (supported by servomechanisms) were used for process control. Occasionally, technologies from one field were applied in another, such as punch card machines that were used for technical scientific computations by some specialized computing bureaus in the US and UK (Campbell-Kelly & Aspray, 1996; Ceruzzi, 1997, 1998).

Engineers and scientists developed the first electronic digital computers during and shortly after the Second World War (Campbell-Kelly & Aspray, 1996; Williams, 1985). During the 1950s, the digital computer started to unite the three fields. Scientists, engineers and manufacturing firms developed and introduced many new computing technologies such as desk calculators, punch card machines, various types of scale models and analog computers (see Figure

1 and Campbell-Kelly & Aspray 1996, and Nijholt & Van den Ende 1994). Several of them were applied in industrial and university research laboratories, which were newly established in this period, performing a range of computational tasks (Reich 1985; Wildes & Lindgren, 1985). Government agencies and firms also applied computing technologies, such as the punch card machine, for their administrative tasks (Yates, 1989). In industry computing devices were used for automatic control, which became an issue especially in the period around the Second World War (Bennett, 1991). Different computing technologies were notably often applied separately by the same organization.

In this period of 1900-1960 price-performance improvements were much smaller than in later periods. Clear statistics are not available, but the development of the punch card machine is a telling example. Punch card machines were introduced in the US in the 1890s for the census, and spread to other countries and applications in the beginning of the 20th century. In the period 1920-1960, punched-card machines became faster and more versatile, but their costs grew faster than labor costs. In 1925, in the Netherlands a tabulating machine cost ƒ2100 per year to rent, approximately equivalent to one-and-a-half years' salary for a machine operator. In 1957 the rent of the machine had risen to ƒ20,000 per year, four years' salary (Van den Ende, 1994b, pp. 173-174). Productivity improvements seem only to have been slightly higher. Limited improvement of computing technology in terms of price-performance stemmed from the fact that computing technology was based on mechanical and electrical knowledge that already existed at the end of the nineteenth and beginning of the twentieth century. No fundamental new knowledge was applied or developed.

We discuss two cases of specific users to indicate the relative importance of the effects on computing technologies, both from the Netherlands: tidal calculations and statistical data processing. These cases are representative for other uses of computing technology in this era, also in other countries; indeed the scope of the kind of uses that computing technology was put to might be larger in the Netherlands than elsewhere. The first case is an example of technical scientific calculations, the second one of data processing. The two cases were large-scale applications of computing technology in this period.

Tidal calculations

In the Netherlands, tidal calculations are used to predict changes in the tidal pattern and water levels during storms, as part of a preparation for hydraulic works that served to reclaim land from the sea and to protect the land against floods (Van den Ende, 1992, 1994b). These works involved the enclosure of the Zuiderzee (now IJsselmeer) by a 30 kilometers dam between 1918 and 1932, and the so-called Delta Works, carried out between the mid 1950s and 1986. In the second half of the nineteenth century civil engineers had applied intuitive methods to predict the effects of hydraulic works on tidal patterns and the propagation of storm surges, and had made simple computational estimates. Between 1900 and 1960 engineers and scientists developed four new methods for these computations: manual computational methods (1918), electrical analogue computing methods (1945), large hydraulic models (1948), and the digital computer (1956).

The Zuiderzee works were the first for which the old intuitive computational methods were considered to lack the required accuracy. Civil engineers, local and regional authorities and members of parliament demanded better computations. A team of engineers, led by the then famous physicist H.A. Lorentz worked for eight years to produce exact calculations to predict the changes in water movements after the dam was completed. They spent numerous months on manual computing work alone. Their predictions were very close to the actual increases in tidal movements. This method of manual computing was practiced on a much larger scale in the 1930s, when a standing team of engineers of substantial size was created just to perform such calculations for the Delta works. The southwest of the Netherlands, the estuary of the rivers Rhine, Meusse and Schelde, was in need of protection from the North Sea. A danger that proved real when in 1953 this region was flooded. Experiments started in the mid-1940s, resulted in the construction of two large analogue computers for this problem in the 1950s and 1960s, a case in point of the second model. Furthermore, large scale-models, the third method, were constructed for the same purpose towards the end of the 1940s. In 1956 for the first time a digital computer was applied. Civil engineers applied the four methods constructed for the purpose in parallel.

This case demonstrates that the size of computing activities for the planning of hydraulic works increased considerably in the course of time, and that the people involved developed or applied several new computing technologies. There was significant and increasing pressure, such as from politicians and municipalities, to get accurate estimates about the consequences of projected hydraulic plans, on water levels and currents. The increasing complexity of the hydraulic works, covering large and geometrically complex areas, was an additional stimulus. The complexity of civil works is a demand factor, since it concerns technological developments in fields other than computing technology, reflecting broader societal demands and needs. Engineers involved in the development of new computing technology, with a background in civil engineering, entered foreign technical fields such as electrical engineering to solve the problems they faced. An ever-greater number of alternatives had to be evaluated with an ever-greater precision, so that each party would get insight into the consequences of projected works.

Advances in the knowledge of computing technologies, however, were of minor influence. Scale models, for instance, were already available before, but were not applied because they were still considered too expensive for the tasks that had to be performed. Lorentz explicitly rejected the idea of building a scale model for the Zuiderzee works because he considered it too expensive (Staatscommissie, 1926). Analog computing technology was applied readily after its development, but nevertheless the new technology did not provide major price-performance improvements compared to prior technologies. Computing technology some provided improved possibilities, for instance to make series of calculations on the same project in a short time, but at a much higher price.

The impacts of the introduction of the new computing technologies were thus limited. It facilitated the evaluation of and discussions about hydraulic plans, but if it had not been available, the evaluations could continue to be executed manually as before. The different kinds of computing technologies were not used outside the field of hydraulic engineering, limiting their societal impact. Manual computing remained in use well into the 1950s. The conclusion should then be that new technologies would not have been applied much earlier if they had been available, and that the application of these technologies depended on the growing demand for computing aids.

Statistical data processing

The same pattern can be found in the field of government statistics (Van den Ende, 1994a, 1994b). Between 1900 and 1960, Statistics Netherlands (CBS) applied an increasing number of desk calculating machines and punch card machines for its operations. In the beginning of the century CBS performed all necessary computations manually. For large assignments large numbers of temporary workers were hired. In 1916, during reorganization, it acquired punch card machines for the department that compiled trade statistics. Only in the 1930s did the number of such machines in use start to grow. Around 1950 the Bureau counted about 60 machines processing punched cards, operated by about 200 employees, processing millions of punched cards each year. In 1960 Statistics Netherlands introduced the digital computer, a particularly expensive device at that time.

The statistical office responded to the growing demand from government agencies and others for statistics. It compiled a growing number of statistics in the course of the century, while the accuracy required and the quantity of available primary data grew. The much more active economic policy of the Dutch government that started before and continued after the Second World War was an important stimulus for the extension of statistical activities. Especially from the late 1950s onward economic and social policy was actively trying to influence society and the economy with the construction of the welfare state (Van Zanden, 1996). There was thus growing demand for new computing technology. Compared to punch card machines the digital computer could perform more calculations and could integrate a number of operations in a single program. However, digital computers were very expensive compared to other technologies, and prone to failures.

Developments in computing technology can therefore hardly explain the growing degree of application of computing technologies. Most technologies would not have been applied before even if they had been available. The punch card technology and the digital computer technology from the 1950s most probably would not have been applied by the Bureau in 1930, because the smaller workload, the smaller number of tables required, and the lower accuracy requirements of the data processing operations would not have justified its application. Price-performance improvements of punch card and digital computing technology were minor. As we noted before, only after the introduction of microelectronics in the 1960s was the digital computer adopted rapidly. Its application in 1960 needs to be explained by the ever-growing quantity of statistical work to be performed and not by the new possibilities on offer.

For explaining early development and diffusion of the digital computers demand factors were dominant. Growing demand from the military was important in explaining the genesis of digital computing technology. However, compared to earlier technologies in use, the digital computers offered some advantages over its alternatives, as the cases discussed here show. The first atomic bombs, e.g., could not have been developed without computers (Nijholt & Van den Ende, 1994). In terms of price-performance, the digital computer was comparable to prior technologies. The improved possibilities it offered came at a much higher cost. The slow pace with which the digital computer developed and diffused has to be explained by the lack of demand for them. For many applications, and probably even for the development of the atomic bomb, traditional technologies could have sufficed without much additional costs.

The degree of new technological knowledge embodied in the first digital computers compared to prior computing technologies was limited. The most important developments concerned the composition of different components; components that had already been developed and applied in computing technology before.[13] In 1962, J. Mauchly and J.P. Eckert, who build the famous ENIAC, which is often considered the first electronic computer, commented that most

[13] The digital computer is thus an architectural innovation in the sense of Henderson & Clark (1990): a new combination of existing technological elements.

of the knowledge that they used had already been available ten to fifteen years before (Nijholt and Van den Ende 1994, 153).

4 Conclusion

Development of computing technology has gone through three different phases: a demand enabled period between 1900 and 1960, and two knowledge enabled periods. The period between 1960 and 1990 was enabled by knowledge development in the field of microelectronics, while the period from 1990 to in fact the present was mainly enabled by knowledge developed for converging computing and telecommunications technology. In both of the latter periods, the speed of knowledge development strongly improved price-performance ratios, thus allowing for this technology to begin having a significant effect on society and the economy. If, then, 'technological revolutions' are periods in which technological knowledge exerts a pervasive influence on society, the computer revolution started around 1960, changed its character around 1990, and continues to the present day. In this view, in the demand enabled period the main instigator of new paradigms, such as the punched card and scale model paradigms, was increased demand. There was no fundamental new knowledge enabling their development. Also the invention of the digital computer in the (late) 1950s was demand enabled and was not at the center of the IT technology revolution. This means that advances in scientific and technological knowledge are not always the main instigator of new technological paradigms, but that they may also find their origin in demand changes. Moreover, their further course of development can primarily be enabled by technological developments instead of demand. No doubt similar examples in other fields can be found.[14] As such, evolutionary economic theorizing on technological development is in need of broadening its framework and recognizing that demand and supply sometimes interact or play alternate roles.

[14] A possible contemporary examples of a radical new paradigm generated by demand, in this case wider social demand articulated by governments, may be energy generated by renewable technologies, such as windmills.

References

Abbate, J. (1999) *Inventing the Internet*. Cambridge, MA: MIT Press.

Achilladelis, B., and Antonakis, N. (2001) The dynamics of technological innovation: the case of the pharmaceutical industry. *Research Policy* 30, 535-588.

Alexander, A.J., and Mitchell, B.M. (1985) 'Measuring Technological Change of Heterogeneous Products'. *Technological Forecasting and Social Change* 27 (2/3): 161-195.

Arthur, B. (1988)'Competing technologies: an overview', in Dosi et al. (eds.), *Technical Change and Economic Theory*. London: Pinter, 590-607.

Aversi, R., Dosi, G., Fagiolo, G., Meacci, M., and Olivetti, C. (1999) "Demand Dynamics with Socially Evolving Preferences", *Industrial and Corporate Change* 8(2): 353-408.

Ayres, R.U. (1985) 'A Schumpeterian Model of Technological Substitution', *Technological Forecasting and Social Change* 27: 375-383.

Beniger, J.R. (1986) *The Control Revolution. Technological and Economic Origins of the Information Society*. Cambridge MA: Harvard University Press.

Bennett, S. (1991) 'The Industrial Instrument - Master of Industry, Servant of Management. Automatic Control in the Process Industries, 1900-1940' *Technology and Culture* 32: 69-81.

Bijker, W.E., Hughes, Th..P., and Pinch, T.J. (eds.) (1987) *The Social Construction of Technological Systems*. Cambridge, MA: MIT Press.

Bijker, W.E., and Law, J. (eds.) (1992) *Shaping Technology, Building Society*. Cambridge, MA: MIT Press.

Braun, E., and MacDonald, S. (1978) *Revolution in Miniature. The History and Impact of Semiconductor Electronics.* Cambridge: Cambridge University Press.

Campbell-Kelly, M., and Aspray, W. (1996) *Computer. A History of the Information Machine*. New York: BasicBooks.

CBS (2002) *Producentenprijzen naar ProdCom, vanaf 1995* (ProdCom Producer prices since 1995). Voorburg/Heerlen: Dutch Central Bureau of Statistics.

Ceruzzi, P.E. (1997) 'Crossing the Divide: Architectural Issues and the Emergence of the Stored Program Computer, 1935-1955' *IEEE Annals of the History of Computing* 19(1): 5-12.

Ceruzzi, P.E. (1998) *A History of Modern Computing*. Cambridge, MA: MIT Press.

Colton, K.W., and Kraemer, K.L. (1980) *Computers and Banking. Electronic Funds Transfer Systems and Public Policy.* New York: Plenum Press.

Coombs, R., Saviotti, P. and Walsh, V. (1987) *Economics and Technological Change*. Houndmills: MacMillan.

De Sola Pool, I. (1990) *Technologies without Boundaries. On Telecommunications in a Global Age.* Cambridge, MA: Harvard University Press.

Dosi, G. (1982) "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change" *Research Policy* 11: 147-162.

Dosi, G. (1988) 'The nature of the innovative process'. In: G. Dosi et al. (eds.), *Technical Change and Economic Theory*. London: Pinter, 221-235.

Dosi, G., Freeman, Ch., Nelson, R., Silverberg, G., and Soete, L. (eds.) (1988) *Technical Change and Economic Theory*, London: Pinter.

Dosi, G., Malerba, F., and Orsenigo, L. (1993) "Evolutionary Regimes and Industrial Dynamics" In: L. Magnusson (ed.) *Evolutionary and Neo-Schumpeterian Approaches to Economics.* Boston: Kluwer.

Freeman, Ch. (1997) 'The Political Economy of the Long Wave'. In: A. Tylecote and J. van Straaten (eds.) *Environment, Technology and Economic Growth.* Elgar: Cheltenham.

Freeman, Ch., and Perez, C. (1988) ‘Structural crises of adjustment, business cycles and investment behavior’. In: G. Dosi et al. (eds.) *Technical Change and Economic Theory*. London: Pinter, 38-66.
Georghiou, L., Metcalfe, J.S., Gibbons, M., Ray, T., and Evans, J. (1986) *Post-Innovation Performance: Technological Development and Competition.* London: MacMillan.
Goldstine, H.H. (1972) *The Computer from Pascal to Von Neumann*. Princeton: Princeton University Press.
Gordon, R.J. (1989) ”The Postwar Evolution of Computer Prices”. In: D.W. Jorgenson and R. Landau (eds.) *Technology and Capital Formation*. Cambridge, MA: MIT Press.
Henderson, R.M., and Clark, K.B. (1990) “Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms” *Administrative Science Quarterly* 35: 9-30.
Jorgenson, D.W., Stiroh, K.J. (2000) “Raising the Speed Limit. U.S. Economic Growth in the Information Age”. *Brookings Papers on Economic Activity* 1: 125-235.
Kemp, R. (1994) ‘Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts’. *Futures* 26(10): 1023-1046.
Knight, K.E. (1985) “A Functional and Structural Measurement of Technology” *Technological Forecasting and Social Change* 27(2/3): 107-127.
Langlois, R.N. (1992) ‘External Economies and Economic Progress. The Case of the Microcomputer Industry’. *Business History Review* 66(1): 1-50.
Levinthal, D.A. (1998) “The slow pace of rapid technological change. Gradualism and Punctuation in Technological Change.” *Industrial and Corporate Change* 7(2), 217-247.
Mahoney, M.S. (1988) ‘The History of Computing in the History of Technology’. *Annals of the History of Computing* 10 (2): 113-125.
Malerba, F., and Orsenigo, L. (1997) ‘Technological Regimes and Sectoral Patterns of Innovative Activities’, *Industrial and Corporate Change* 6(1): 83-117.
Metropolis, N., Howlett, J., and Rota, G.-C. (eds.) (1980) *A History of Computing in the Twentieth Century*. New York: Academic Press.
Michie, R.C. (1999) *The London Stock Exchange. A History.* Oxford University Press, New York.
Molino, A.H. (1999) ‘Understanding the role of the technical in the build-up of sociotechnical constituencies’. *Technovation* 19: 1-29.
Moschovitis, Ch.J.P., Poole, H., Schuyler, T., and Senft, Th.M. (1999) *History of the Internet*. Santa Barbara, Cal.: ABC-Clio.
Mowery, D., and Rosenberg, N. (1979) ‘The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies’. *Research Policy* 8: 103-153.
Nelson, R.R., and Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap, Harvard University Press.
Nightingale, P., and Poll, R. (2000) Innovation in Investment Banking: The Dynamics of Control Systems within the Chandlerian Firm. *Industrial and Corporate Change*, 9(1): 113-141.
Nijholt, A., and Van den Ende, J. (1994) *Geschiedenis van de rekenkunst. Van kerfstok tot computer*. Schoonhoven: Academic Service.
OECD (1992) *Technology and the Economy. The Key Relationships*. Paris: OECD.
Queisser, H. (1988) *The Conquest of the Microchip.* Cambridge, MA: Harvard University Press.
Reich, L.S. (1985) *The Making of American Industrial Research. Science and Business at GE and Bell, 1876-1926.* Cambridge: Cambridge University Press.
Rip, A., and Kemp, R. (1998) “Technological Change”. In: Rayner, S., and Malone, L. (eds.), *Human Choice and Climate Change*, Vol. 2, Resources and Technology, Washington DC: Batelle Press, 327-400.
Rothwell, R. (1992) Successful industrial innovation: Critical success factors for the 1990s. *R&D Management* 22(3): 221-239.

Sahal, D. (1981) *Patterns of Technological Innovation*. Reading, Mass.: Addison Wesley.

Saviotti, P.P. (1985) 'An Approach to the Measurement of Technology Based on the Hedonic Price Method and Related Methods'. *Technological Forecasting and Social Change* 27: 309-334.

Saviotti, P.P., Stubbs, P.C., Coombs, R.W., and Gibbons, M. (1982) 'An Approach to the Construction of Indexes of Technological Change and of Technological Sophistication: The Case of Agricultural Tractors'. *Technological Forecasting and Social Change* 21: 133-148.

Schmookler, J. (1966), *Invention and Economic Growth*. Cambridge, MA: Harvard University Press.

Schumpeter, J.A. (1952 [1943]) *Capitalism, Socialism, and Democracy*. London: George Allen and Unwin.

Scott Morton, M.S. (ed.) (1991) *The Corporation of the 1990s. Information Technology and Organizational Transformation.* New York: Oxford University Press.

Smith, M.R., and Marx, L. (eds.) (1994) *Does Technology Drive History?* Cambridge, MA: MIT Press.

Staatscommissie Zuiderzee (1926) *Verslag van de Staatscommissie Zuiderzee*. 's-Gravenhage: Landsdrukkerij.

Tidd, J. Bessant, J., and Pavitt, K. (2001) *Managing Innovation. Integrating Technological, Market and Organizational Change*. Wiley: Chichester, 2nd ed.

Van den Ende, J. (1992) 'Tidal Calculations in The Netherlands, 1920-1960'. *IEEE Annals of the History of Computing* 14(3): 23-33.

Van den Ende, J. (1994a) 'The Number Factory: Punched-Card Machines at the Dutch Central Bureau of Statistics'. *IEEE Annals of the History of Computing* 16 (3), 15-24.

Van den Ende, J. (1994b) *The Turn of the Tide. Computerization in Dutch Society, 1900-1965*. Delft: Delft University Press.

Van den Ende, J. and Kemp, R. (1999) 'Technological transformations in history: how the computer regime grew out of existing computing regimes'. *Research Policy* 28: 833-851.

Van Zanden, J.L. (ed.) (1996) *The Economic Development of the Netherlands since 1870*. Cheltenham: Elgar.

Venkatraman, N. (1991) 'IT-induced Business Reconfiguration'. In: M.S. Scott Morton (ed.), *The Corporation of the 1990s. Information Technology and Organizational Transformation*. New York: Oxford U.P., 122-157.

Vincenti, W.G. (1994) 'The Retractable Airplane Landing Gear'. *Technology and Culture* 35:1-33.

Wildes, K.L., and Lindgren, N.A. (1985) *A Century of Electrical Engineering and Computer Science at MIT, 1882-198.*, Cambridge, MA: MIT Press.

Williams, M.R. (1985) *A History of Computing Technology*. Englewood Cliffs: Prentice Hall.

Yates, J. (1989) *Control through Communication. The Rise of System in American Management* Baltimore/London: Johns Hopkins.

Publications in the ERIM Report Series Research[*] in Management

ERIM Research Program: "Organizing for Performance"

2002

Trust and Formal Control in Interorganizational Relationships
Rosalinde Klein Woolthuis, Bas Hillebrand & Bart Nooteboom
ERS-2002-13-ORG

Entrepreneurship in China: institutions, organisational idendity and survival. Empirical results from two provinces.
Barbara Krug & Hans Hendrischke
ERS-2002-14-ORG

Managing Interactions between Technological and Stylistic Innovation in the Media Industries. Insights from the Introduction of eBook Technology in the Publishing Industry
Tanja S. Schweizer
ERS-2002-16-ORG

Investment Appraisal Process in the Banking & Finance Industry
Mehari Mekonnen Akalu & Rodney Turner
ERS-2002-17-ORG

A Balanced Theory of Sourcing, Collaboration and Networks
Bart Nooteboom
ERS-2002-24-ORG

Governance and Competence: How can they be combined?
Bart Nooteboom
ERS-2002-25-ORG

ISO 9000 series certification over time: What have we learnt?
Ton van der Wiele & Alan Brown
ERS-2002-30-ORG

Measures of Pleasures: Cross-Cultural Studies and the European Integration
Slawomir Magala
ERS-2002-32-ORG

Adding Shareholders Value through Project Performance Measurement, Monitoring & Control: A critical review
Mehari Mekonnen Akalu & Rodney Turner
ERS-2002-38-ORG

Web based organizing and the management of human resources
Jaap Paauwe, Rolf Visser & Roger Williams
ERS-2002-39-ORG

---

* A complete overview of the ERIM Report Series Research in Management:
http://www.ers.erim.eur.nl

ERIM Research Programs:
LIS Business Processes, Logistics and Information Systems
ORG Organizing for Performance
MKT Marketing
F&A Finance and Accounting
STR Strategy and Entrepreneurship

Challenging (Strategic) Human Resource Management Theory: Integration of Resource-based Approaches and New Institutionalism
Jaap Paauwe & Paul Boselie
ERS-2002-40-ORG

Human Resource Management, Institutionalisation and Organisational Performance: a Comparison of Hospitals, Hotels and Local Government
Paul Boselie, Jaap Paauwe & Ray Richardson
ERS-2002-41-ORG

The added value of corporate brands: when do organizational associations affect product evaluations?
Guido Berens, Cees B.M. van Riel & Gerrit H. van Bruggen
ERS-2002-43-ORG

High Performance Work Systems: "Research on Research" and the Stability of Factors over Time
Paul Boselie & Ton van der Wiele
ERS-2002-44-ORG

Diversification and Corporate Governance
George W. Hendrikse & Aswin A..C..J. Van Oijen
ERS-2002-48-ORG

Governance Structure, Product Diversification, and Performance
Aswin A. Van Oijen & George W. Hendrikse
ERS-2002-51-ORG

Global Sourcing: Fad or Fact?
Michael J. Mol, Rob J.M. van Tulder, Paul R. Beije
ERS-2002-55-ORG

Internationalization Of Management Buyouts: Firm Strategies And Venture Capitalist Contribution
Mike Wright, Andy Lockett, Paul Westhead, Hans Bruining
ERS-2002-58-ORG

The Importance Of Customer Satisfaction In Organisational Transformation: A Case Of A Dutch Temporary Employment Agency
Martijn Hesselink, Ton van der Wiele and Paul Boselie
ERS-2002-60-ORG

A Study On The Applicability Of SERVQUAL Dimensions For Web Sites
Jos van Iwaarden, Ton van der Wiele
ERS-2002-61-ORG

Entrepreneurial Orientation In Management Buy-Outs And The Contribution Of Venture Capital
Hans Bruining and Mike Wright
ERS-2002-67-ORG

The odd role of proximity in knowledge relations - High-tech in The Netherlands
Gerben van der Panne, Wilfred Dolfsma
ERS-2002-75-ORG

Organizing as Improvisations (Methodological Temptations of Social Constructivism)
S. Magala
ERS-2002-76-ORG

Best Practice in Company Standardisation
Florens J.C. Slob, Henk J. de Vries
ERS-2002-81-ORG

Standardisation education
Henk J. de Vries
ERS-2002-82-ORG

Elective Identities
(Culture, Identization And Integration)
Slawomir J. Magala
ERS-2002-92-ORG

Technology Push, Demand Pull And The Shaping Of Technological Paradigms -
Patterns In The Development Of Computing Technology
Jan van den Ende & Wilfred Dolfsma
ERS-2002-93-ORG

Modes of governance of new service development for mobile networks.
A life cycle perspective
Jan van den Ende
ERS-2002-94-ORG

The Development Of Mutual Trust In British Workplaces Through 'Partnership': Conceptualisations, Definitions And Experiences.
Graham Dietz
ERS-2002-97-ORG

Why Do European Venture Capital Companies Syndicate?
Sophie Manigart, Andy Lockett, Miguel Meuleman, Mike Wright, Hans Landström, Hans Bruining, Philippe Desbrières, Ulrich Hommel
ERS-2002-98-ORG