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Development of ICT as an evolutionary process*

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<Abstract>

The research shows how the technological change of 'Information and Communication Technology' (ICT) is accompanied with the usage change. It aims to provide a better conceptualization with empirical findings about the fact that the technological development of ICT is a convergence process of ICT factors with the usage of ICT moving from a limited coverage toward a general-purpose. The research adapts a descriptive methodology on a historical matter and demonstrates how it can be conducted through analytical description of Input-Output tables (I/O) the over periods. The case is about the UK with sequential I/O during 1970s- 90s.

Keywords: ICT, evolution, convergence, general-purpose technology, Input-Output tables (I/O).

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1. Introduction

Regarding the expansion of computers and their impact in the early 1960s, Machlup (1962) opened the study about the emerging information economy. Fifteen years later there was an achievement by Porat (1977), who also focused on information-related activities. Not long after Freeman and colleagues (1982, 1988, 1997) had defined 'Information and Communication Technology' (below, ICT) as the convergence of the computer and telecommunication technology and they focused more on the technological aspects from the perspective of long-term structural changes. Recently, Hawkins, Mansell and Steinmueller (1997) included media in an expanding the ICT category.

Following Freeman's definition of the ICT, the research argues that the technological development of the ICT is a convergence process of the ICT factors with the usage of ICT moving from a limited coverage toward a general-purpose. It focuses on how the technological change of ICT is accompanied with the usage change. It has been conducted through an analytical description of Input-Output tables (below, I/O) over periods. The research reflects on a historical matter rather than an examination with arguments. It simply aims to provide better conceptualisation with the empirical findings.

As a practical issue pursuing an empirical study, it need to be defined the boundary of the ICT. Here, this research holds Miles and Matthews (1989), which is one of the earliest preparation for the empirical study about the ICT and becomes a basement of OECD's ICT criteria, and which includes the components of the ICT covering semiconductors, computer equipments, computer services, communication equipments and telecommunications.

In section 2, it will be discussed what is an evolutionary process. It will be asserted that the evolutionary process is beyond a simple biological metaphor and a way of considering technological development interacting with non-technological factors. In section 3, the technological change of the ICT will be traced through each technological development of semiconductors, computers and telecommunications. Their strengthened inter-linkage and further convergence over the periods will be detected. In section 4, the changing pattern of ICT will be traced from the experiences of the UK. It will be conducted through the I/Os tables from the mid-1970s to mid-1990s. In the final section, empirical findings will be interpreted as supporting the argument that the process of the ICT development is an evolutionary process and further part of co-evolutionary process. It will be concluded with denoting what is necessary in preparing for the next step of ICT.

2. Theoretical discussion: An evolutionary process.

Before entering into an empirical examination for the evolutionary process of the ICT development, it would be useful to clarify what is 'evolution' in comparison with 'development' and 'change'. Oxford English Dictionalry defines 'evolution' as 'the gradual development of something, especially from simple to a more complex form.' It might be a common sense about evolution. However, there are certain ambiguities in terms of what are differences among 'evolution', 'development' and 'change'. Even though 'evolution', 'development' and 'change' are somehow interchangeable in a common language, the differences among them must be given an emphasis all the more. Following definition on the same dictionary, 'change' focuses on the difference itself, regardless reversible or irreversible in the direction of change. Compared to 'change', 'development' and 'evolution' mean a certain change having a direction toward more advanced and/or complicated.

The difference between 'development' and 'evolution' is also distinguishable. As a simile, 'evolution' is a biological process compared to 'development' as a chemical process.[1] Typically in biology, selection and/or adaptation explain the process of evolution. As a dominant evolutionary theory in biology, Darwinian theory insists on the natural selection and mutation in the process: natural selection chooses variants, which enhances survival and reproduction. Lamarkian explains the process through the adaptation, which is out-of-date explanation in the present theory of biological evolution after gene being found as the transfer of the biological evolution.

Nowadays, 'evolution' is a pervasively used terminology not only in biology but also in outer-biology. Particularly in dealing with relevant issues with technological changes, there have been persistent attempts to interpret the change/development in organisations and institutions, from the firm level to political-social systems, as an 'evolutionary' process.[2] *An Evolutionary Theory of Economics* by Nelson and Winter (1982) is one of landmarks in this approach, so-called Evolutionary Economics. It formulates a family model where firms are not only selected by the economic system but also adapted through modifying their behaviours. Based on the firm as a unit of the evolutionary process, the behaviour of firm is interpreted as 'search' for survival and the formulated behaviour as 'routine'. On the process, the technology has dual functions: technological 'change' as the source of variant of the whole evolving structure/mechanism; technological 'development' as a path of evolution of the firm and the whole structure/mechan-

1) As a simile, a 'change' on this content is a physical process, in terms of classical physics or mechanics.

2) As a general introduction, Anderson(1994) and Margnusson (1994) are useful. For reviewing recent debate in applying evolutionary theory to economics, see Resenberg (2000) and Hodgson (2002).

ism.[3]

Technological evolution on Figure 1 describes the different stage of technological development with dot circles:[4] new technology; expanding application; generalized technology. In each stage, different environment is corresponded or matched. The environment covers organizations, institutions, industries and so on. On the same figure, an industrial cluster is described to focus on usage aspects. The figure means that each technological development stage brings newly a corresponding environment and the new environment also brings further technological development stage.[5]

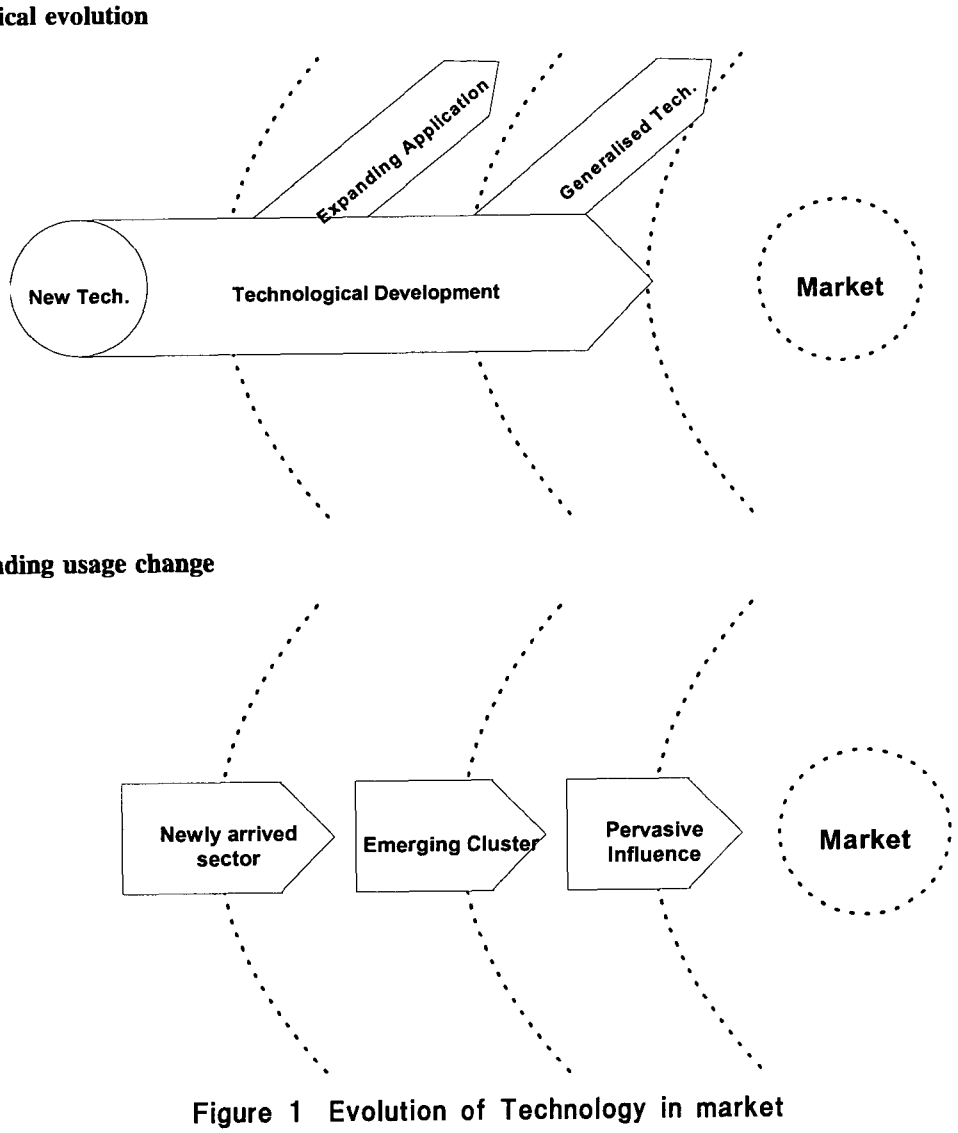


Figure 1 Evolution of Technology in market

3) Technological 'evolution' is intentionally avoided in the interpretation of Nelson's and Winter's. The distinction among 'evolution' 'development' and 'change' discussed on the above will be kept during the interpretation and should be reminded.

4) It is an analogue of the magnetic field in physics.

5) It is a simple version of the theory of technological paradigm. For details, see Freeman's and Perez's(1988).

During the process, main driving forces in each stage, which is expressed as dot circle on figure, can be distinguished. On the expanding application stage, user-interface has a critical importance. When it approaches to general technology, the importance of other technological development is getting crucial.

The usage aspect can be described as followings: limited user or newly arrived sector; expanding user or emerging cluster; pervasive influence. Between technological development and usage, there must be certain corresponding or matching relationship. If there is a mismatch between them, the whole process will be confronted with a bottleneck. Similarly but more generally, the technological evolution can be persistent with a corresponding environmental change.

One important aspect is such that, despite of those trends, the change also brings some of divergence and further segregation in many ways. For instance, the gab or polarisation of the ICT usage could bring a serious issue for the next step of the ICT development. Rather than remaining on an optimistic prospect to the ICT development, there is a growing precaution on skill degradation and income dispersion linked with it. Keeping in mind the importance of non-technological factors in the ICT development,[6] the prospective efforts (i.e. foresight, technology road-map, etc) could be well better prepared through combining technological development, in a narrow sense, to the coverage and trend of usage. However, the research remains on a limited issue, rather than covering overall issues mentioned.[7]

3. Technological development

3.1. Seeds of ICT from semiconductors and computer

The development of the semiconductor might be regarded as the seed of sequential technological change in ICT. Technological change in semiconductors towards being faster, smaller and cheaper, allowed similar paths of advance for Computer and Telecommunication equipment. Since the invention of the transistor, the increase of integration with mass production has led to sharp relative price declines relative to performance increase, and stimulated the expansion of the computer. The development of the semiconductor also brought digitalization in telecommunication, the realization of optical transmission, and satellite transmission.

After the invention of transistor in 1947, sequential inventions of the junction transistor in 1951 and the use of silicon as an appropriate material for semiconductivity in 1954 becomes the seed of incoming ICT-era. In the technological improvement of the semiconductor, the next monumental improvement was

6) Cf. Fransman (1996).

7) Hwang(2001) shows empirically how the diffusion of ICT had been accompanied with the change of skills mainly during the 1980s in the UK. Abstract version appears in Hwang and Francesco (2002). Also, Hwang (2003) more focuses on methodological issues in tracing coordination between changes in skills and diffusion of ICT. The current paer pins the interaction between technological change and usage change of ICT, emphasising on the importance of usage aspects related to the technological change.

the emergence of the integrated circuit (IC) during the 1960s, which solved the practical problem of the interconnection of transistors within the system. After that, a series of technological exploitations was triggered. The main driving force for the highly integrated semiconductor was the ability to fit more components on to a single chip.

The next leap forward came with the invention of the microprocessor. In 1971, Intel launched the microprocessor, which contained over 2,000 components, compared to a chip in 1963 that included about 30 electronic components. Due to the rapidly decreasing price, increasing power and greater miniaturization, microprocessors have become an integral part of every machine from electronic consumer goods to airplanes.

Microprocessors and memories led to the introduction of the microcomputer by Texas Instruments in 1972. Microprocessors, memory devices and microcomputers established the large-scale integration (LSI) regime. Following the LSI regime, there was a transition from LSI to very large-scale integration (VLSI) and ultra large-scale integration (ULSI). The driver of these advances was process innovation as before, along with related sub-technologies including optical lithography and clean room technology. Recent technological trends involve responding to customer needs with more integrated technology.

The expansion of the computer might be at least one of the core elements in ICT development. The development of the computer was mainly brought about by the semiconductor, particularly in early ICT development. Due to the performance increase, price decline and smaller size of semiconductor devices, high performances, cheap prices and small sizes of computer also resulted. The expansion of the computer brought the need for interconnection of computers and a market for software. Furthermore, computer applications were also rapidly increased, including telecommunication equipment.

During the Second World War, there was a stimulus to the development of the modern computer for military purposes, including deciphering encryption, in Germany, the UK and the USA. After the war rapid progress was made in solving some of the problems of logic design, memory storage systems and programming techniques. The emphasis switched from theoretical analysis to construction. The UNIVAC I, the first commercially available computer, was launched in the USA in 1951 and the USA started its dominance of the computer industry. Though commercial computers were introduced during the 1950s, they were very restrictedly used in certain parts of the economy.

Due to the semiconductor development, the replacement of valves by transistors brought the expansion of computers. The advent of the microprocessor in 1971 allowed faster and cheaper usage of computers. The minicomputer had started during the 1960s due to the advent of ICs but rapidly expanded during the 1970s.

Microprocessors contain the central processing unit essential to a computer's operation in a single chip. The increase in performance and the reduction in size and production costs which resulted from this large

scale integration meant that all of a computer's processing, memory and input/output could be housed in a single box which would sit on a desk. One of the first 'personal computers' was developed by the Apple Corporation. After that, IBM's personal computer (PC) was launched in 1981.[8] Around the same time the workstation was introduced by Apollo in 1981 and Sun Microsystems in 1982. The expansion of the minicomputer and the advent of the PC and workstation caused the 'Big-Bang' of the usage of computers.

3.2. Development of ICT with computers

The power and versatility of the computer derive from the way its hardware and software combine in the processing of data. While the hardware contributes a variety of possible processing operations which have been designed so as to make the computer a general-purpose data processor, what the software does is to select a sequence of these operations which convert the computer to a special purpose processor for the defined task.

The market for programming services, software products, and professional services was stimulated by the expansion of computers and increased demands for application. Although there was already a market for software services, IBM's unbundling policy for software in 1969 greatly affected the software industry. Furthermore, the advent of minicomputers and networked computing during the 1960s created an enormous range of affordable commercial applications for computer systems. The role of software was becoming crucial.

Early in the 1970s, improvements in hardware technology allowed faster real-time access and multi-user software. Despite the expansion of the minicomputer, the applications were very diversified and the size of scale for packaged software was still not large enough. In both mainframes and minicomputers, the problems of software development and maintenance received growing attention during the 1970s.

During the 1980s, economies of scale in the development of software were realized. After seeing the success of open systems, which means a common operating system for different computers, and open architecture, which had already encouraged software companies to develop application programs, IBM adapted the open architecture strategy in its personal computer in 1981. The advent of the IBM-PC was accompanied by MS-DOS as an operating system and DOS became the dominant OS for PCs. In the case of workstations, the most successful company, Sun Microsystems, adopted an open standard involving UNIX, which was already used as an operating system on some microcomputers. For mainframes, realizing economies of scale was achieved by the development of organization-specific software.

In the 1990s, software development also brought

8) Whereas Apple used all its own hardware and software in its PC, IBM design was licensed for manufacture by other electronics companies and soon the IBM PC format began to be *de facto* standard. The IBM PC was built around the Intel 8088 microprocessor, contained 64K DRAM working memory, and ran on Microsoft's MS-DOS operating system.

the wider expansion of computer networks. The launching of the World Wide Web (WWW), which is not software as such but allows user-friendly networking, brought the explosion of the Internet.[9] Now, it is expected that networks provide new entry points for the development of software. Networking increases the necessity of co-ordination between different computers and could bring more compatible surroundings. The result may be the advent of more compatible software as well as more compatible hardware. Both could increase the usage of computers and reduce user requirements.

3.3. ICT expansion through Internet

Since the advent of the computer, the integration between computers and communications is very marked, as shown through technological development, and represents one of the main paths of ICT expansion. Even though the interface between computers and communications was anticipated and was required since the early launch of computers, the lack of 'standards' between different computers remained one of the most significant barriers.

In the development of computer networks, there have been several efforts to increase the level of standardization.[10] As one of most important events, Ethernet appeared in 1973. In origin, it was suggested as a branching broadcast communication system for carrying digital data packets among locally distributed computing stations through a two-way passive bus. It was the first high-speed local area network (LAN) technology to link everything together regardless of different vendors, and became an industry-wide standard in the 1980s following sequential innovations (Spurgeon, 1997).

Another important, or even more important form of standardization occurred through TCP/IP (Transmission Control Protocol/Internet Protocol), which is an open internet working communication protocol. In the late 1960s and early 1970s, the computer network evolved to the form of a wide area network (WAN) including ARPANET. The ARPANET was the oldest of the networks in the ARPA Internet.[11] In ARPANET, soon after launching, there was an increased need to interconnect host to host. In searching for a standard protocol, Ethernet in 1973 and TCP/IP in 1978 were prepared as the working standard of choice. Over the years, it was modified to fit the growing number of networks and hosts connecting to it.

9) Due to the apperaance of the WWW, Mosaic, the first multimedia and graphic user interface web browser software, appeared in 1993 and promoted the expansion of the Internet.

10) In fact, standardisation is an on-going process rather than being achieved in a certain period and certain stage. On the other side, it also raises issues of security. Standardisation and security will remain as focal areas in the evolution of ICT.

11) Originally, the Internet with a capital I referred to the ARPA Internet. Even after the ARPA Internet ceased, the Internet with a capital I keeps its name. here one should recall the difference between the Internet (with a capital I) and internet (with a small i). The Internet (with a capital I) is one internet (with a small i). The internet is 'a collection of communications networks interconnected by bridges and/or routes' as a technical term (Stallings, 1997: 528), or 'an interconnection of computer networks' as a general usage term(Lax, 1997: 103).

Now, TCP/IP networks consist of router-connected subnetworks that are located all over the world. The Internet, which originally came from ARPANET, is based on TCP/IP and provides the basis for the ICT era via the World Wide Web.

In 1990, commercial providers of Internet dial-up access appeared as ARPANET gave way to the Internet. In 1991, the World Wide Web (WWW) appeared on the foundation of HyperText Transfer Protocol (HTTP), which is a protocol for transmitting information with the efficiency necessary for making hypertext jumps (Stallings, 1997: 719). In conjunction with Mosaic, this brought a graphical user interface which allowed commands to be executed using a computer mouse, and reduced the user requirements for accessing the Internet, so much promoting its expansion. Since the first Internet shopping mall in 1994, electronic commerce has been rapidly advancing, and the first Internet Bank appeared in 1999.

4. Usage of ICT: Case of the UK

4.1. Trajectory of ICT usage

Using Miles and Matthew's (1989) boundary of ICT based on current Industry/Commodity classifications (the Standard Industrial Classification of 1980), usage of ICT is traced from a kind of input ratio of semiconductor etc., computer equipment, computer services, telecommunication equipment and telecommunication services through each year's I/O tables: the Domestic Usage table, Import Usage Table and Investment Table (1974, 1979, 1984, 1990, 1995).

The early generation of ICT seems to have evolved mainly on the basis of equipment, from the diffusion pattern. During the 1980s, the expansion of computer equipment became the core of ICT. The explosion of the computer can be regarded as the second generation of ICT. After the 1980s, computer services become more important and show a separate pattern from computer equipment since the mid-1990s. The expansion of telecommunication also accelerates at this time. The explosion of the Internet could be regarded as characterising the expansion of the third generation.

The expenditure on computer equipment input and investment is £657 million in 1974 and had become £9,021 million by 1990. Compared with other hardware parts of ICT, which include electronic components, telecommunication equipment and instrument engineering equipment, the faster expansion of computers is apparent. Computer services are separately treated since the 1990 I/O and show even faster increase than computer equipment,[12] being followed by telecommunication, which appears from the 1984 I/O.

During the 1980s, the hardware part of ICT (hICT) share shows a generally increasing trend. Decom-

12) However, it was also influenced by the boundary change of computer services before and after 1990. The maintenance and repair of computers is included in computer equipment in the 1990 I/O but in computer services since the 1992 I/O balance. Therefore the increase of computer service expenditure between 1990 and 1995 should be lower than the difference based on the table, if same boundary were to be kept, conversely the real increase of computer equipment should be higher. However, despite the boundary chnge, the trend is supported from further comparison of periods, shown later.

Table 1 ICT input and investment: 1974~1995

(unit: £ million)

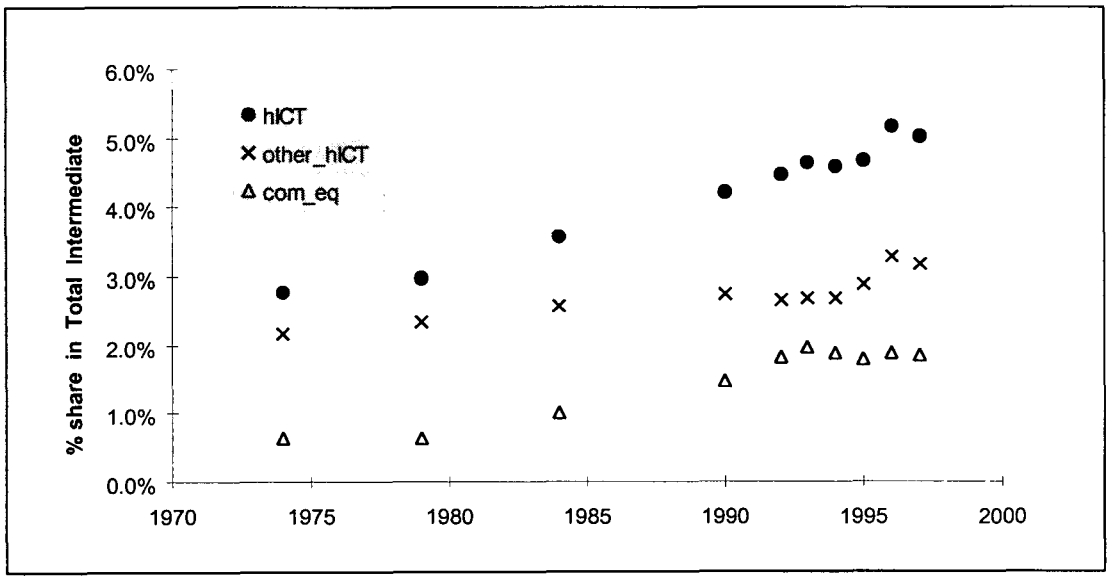
	Input					Investment				
	1974	1979	1984	1990	1995	1974	1979	1984	1990	1995
Computer eq.	155	508	1,395	3,641	6,446	502	904	2,499	5,380	8,534
Other hICT	1,206	3,392	7,037	10,768	17,441	1,079	1,709	2,984	6,093	6,882
computer serv.	n.a.	n.a.	n.a.	9,465	14,117	n.a.	n.a.	n.a.	604	3,217
telecomm.	n.a.	n.a.	4,493	9,264	14,966	n.a.	n.a.	0	0	137
Int. Input / Int. Investment	116,360	90,798	183,577	333,557	505,240	725,527	14,939	35,538	55,388	110,106
Total Intermediate	105,737	219,115	388,945	615,346	841,887					

Key: 'Total Intermediate' = 'Int. (=Intermediate) Input' + 'Int. Investment'.
Source : Own elaboration from each I/O and I/O balance

posing the trend into investment vs. input and into computer equipment vs. other hICT allows more detailed description (Graph 1). Computer equipment investment is believed to be the main driving force of the expansion of hICT, and ICT as a whole, during the 1980s.

In 1974, it was less than half of other hICT investment but increased rapidly during the 1980s and overtakes the investment of other hICT in the early 1990s. During the 1980s, Computer equipment input remained at a relatively low level but the increase of other hICT input was slower than that of computer equipment investment. During the 1990s, the acceleration of hICT investment is slowing down. It

Graph 1 HICT time pattern: 1974~1997



Source : Own elaboration from each I/O and I/O balance

seems that the 1980s is an expansion stage of hICT investment mainly due to computer equipment, and that the 1990s is a relatively mature stage of computer equipment investment.

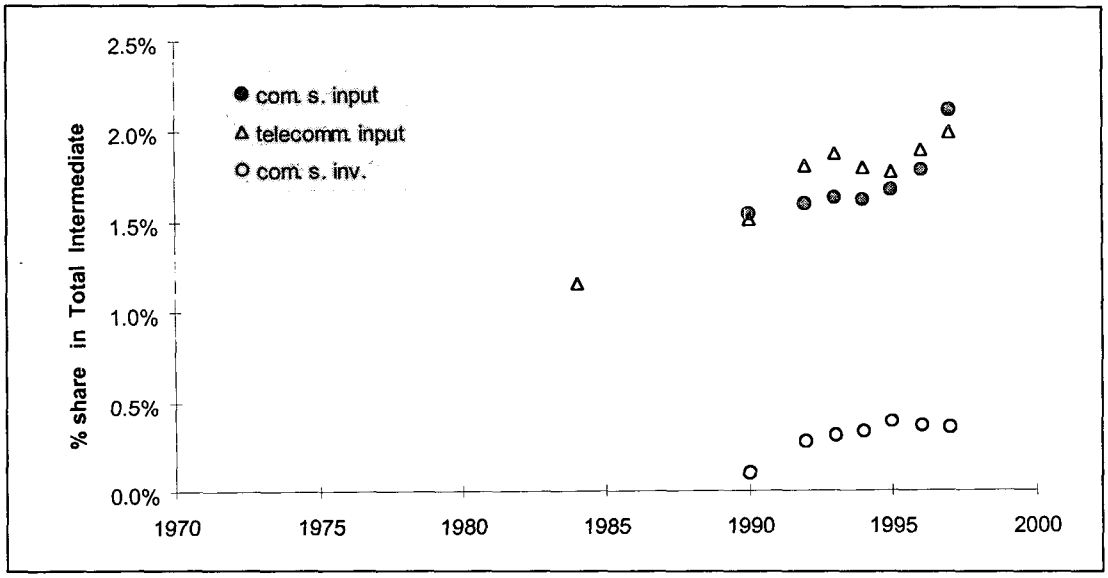
In the case of the software part of ICT (sICT), it is mainly used as input rather than as investment. In tracing sICT, there are serious data limitations for the 1980s. Telecommunication services data are only available from 1984 and the next figure appeared in 1990. Computer services appear from 1990. Alternatively, the unobserved path during 1980s may be traced from the 1990s path with the allowance for technological development.

Telecommunication services seem to have expanded until the early 1990s and re-expanded since the mid-90s. When it started the re-expansion, the telecommunication share shows some similarity to the pattern of computer service input. The computer service input is relatively stable with computer equipment investment during the early 1990s and shows a fast increasing pattern since then. Telecommunication also shows an increasing pattern after the stable pattern in the early 1990s. In the case of computer service investment, it seems to be a steadily increasing pattern in the early 1990s and decline or at least stability after that.

The increasing importance of sICT input suggests the expansion of the next generation of ICT, which involves the merging of computers and telecommunications. The role of telecommunications and computer services have become crucial in the diffusion of ICT since the mid 90s compared with the earlier period. Based on technological change in ICT and the time pattern, the mid-1990s are believed to be a turning point for sICT as well as ICT in general.

When the early computer services before 1990 are approximately traced from the investment pattern of

Graph 2 sICT time pattern: 1984~1997



Source : As for Graph 1.

computer equipment investment and regarded as an upper bound,[13] the share is approximately 1.5% in 1974, and 2.4% in 1984. In the case of computer service investment, the share is relatively small and the error from approximation seems to be negligible, but the error in the service input does not seem to be negligible. However, its pattern during the 1990s suggests a stable relationship with computer equipment investment until the early 1990s. Without further relevant information, the pattern of computer equipment investment is regarded as a proxy for the pattern of computers until the early 1990s.

4.2. Pattern of Industrial usage

The industrial comparison is based on a 25 industry classification, aimed at maintaining consistency from period to period of the industry boundaries in each I/O, mainly through merging various industries. Similar patterns of the usage during the 1980s are clustered and allocated to the same Type:

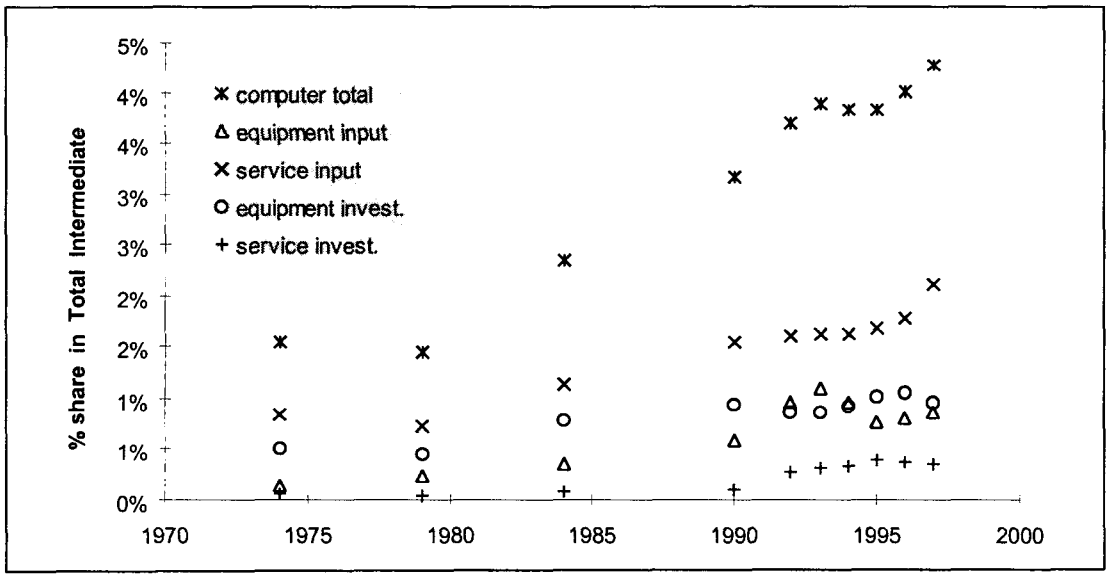
Type Ⅳ increase through the whole 1980s with a high share in the 1970s;

Type Ⅲ decrease in the early 1980s and increase in the later 1980s;

Type Ⅱ decrease through the whole 1980s;

Type Ⅰ increase in the early 1980s and decrease in the later 1980s;

Graph 3 Expansion of Computers: 1974~1997



Source : As for Graph 1.

13) Pre-1990 computer service investment excluding maintenance is traced from its 1990 ratio to computer equipment investment. With the assumption that there is an increasing trend of computer services in total computer investment, the calculated computer service investment based on the 1990 ratio and computer equipment investment is regarded as an upper bound. The ratio in 1990, 0.11, gives shares of computer service investment and of total computer input. In the same way, pre-1990 computer service input is traced from the 1990 ratio to computer equipment input, 4.14, and corresponding computer equipment input.

Type 0 increase through the whole 1980s with a low share in 1970;

Outliers too small a share to detect a reliable pattern.

Generally speaking, high-technology industries show later diffusion stages. However, the patterns display many interesting aspects. A high level of introduction in the early generation seems to delay the acceptance of the next generation. The delay depends on the industry characteristics related to ICT as well.

(1) Computer equipment in Non-service sector.

Chemicals remained at a low rank until 1992 after its 2nd rank in 1979. The high investment during the late 1970s seems to have delayed the acceptance of the next generation of ICT in this industry. Similarly, the high investment in oil processing in 1984 was followed by a relatively slow acceptance in following periods. This suggests that there could be the possibility of a lock-in effect of the early generation of technology in a fluid process system requiring huge investments.

Electronics also showed a decline in rank during the 80s but remained at a relatively high rank. The industry's characteristics seem to have lessened the lock-in effect. In the case of Vehicles, it continuously remained at a high rank until 1990 but shows a lower rank in 1992. This suggests that the Vehicle industry is one of those most influenced by ICT. In the case of Machinery, although it shows a continuous expansion path in the acceptance of ICT, its relatively slow expansion during the 80s is shown by its lower rank in those years.

Type 0 industries rose to high rank during the 1980s. As late to take-off in ICT, they become fast acceptors of the evolving ICT. These phenomena raise interesting research questions related to investment strategy etc., concerning how the diffusion of the emerging new technology is associated with early investment and the industry characteristics. However, it is left as another research topic beyond the present thesis, which focuses on the investigation of how the diffusion pattern is related to skill changes.

Type Ⅳ : up - up

Machinery : steady increasing path regardless of price adjustment. With an already relatively high share of computer investment in 1974, it is regarded as Type Ⅳ. Printing : Without a possible business cycle effect, the share in 1984 might be lower. With regard to its early involvement in ICT during the 1970s,[14] it is treated as Type Ⅳ rather than Type 0.

Type Ⅲ : down - up

Electronics : steady decreasing pattern (Type Ⅱ) without the price adjustment, but down-up pattern (Type Ⅲ) with the price adjustment. Without a possible business cycle effect, the share in 1984 might be lower. With consideration of the business cycle effect, it is regarded as Type Ⅲ.

14) In the case of Print and paper industry, even the level is not very high before the 1980s but seems to be already involved in ICT during 1970s. During 1970s-1980s, the Print and paper industry became involved in the technological achievements related to the development of ICT.

Type Ⅱ : down - down

Chemical : steady decreasing pattern regardless of price adjustment. Construction : steady decreasing pattern regardless of price adjustment.

Type Ⅰ : up - down

Vehicle : up-down pattern (Type Ⅰ) without the price adjustment but steady increasing pattern (Type Ⅳ) with a price adjustment. Without a possible business cycle effect, the share in 1984 might be lower but the figure might still be bigger than that in 1979. It is regarded as Type Ⅰ. Metal : increasing pattern during the early 1980s and decreasing during the later 1980s regardless of price adjustment. Clothing : increasing pattern during the early 1980s and decreasing during the later 1980s regardless of price adjustment. Oil processing : increasing pattern during the early 1980s and decreasing during the later 1980s regardless of price adjustment.

Type 0 : up - up

Food, Cement, Furniture, Energy : steady increasing path regardless of price adjustment. With a relatively low share of computer investment in 1974, these are regarded as Type 0.

Outlier

Oil extraction : it is too strongly influenced by the external conditions, the namely Oil shocks during the 1970s and the development of North Sea Oil, and treated as an outlier as well. The development of North Sea Oil and the Oil shocks during the 70s seems to influence the other energy sector as well. Its path needs caution.[15)]

Agriculture, Mining and Water : the investment in computer equipment until 1990 is relatively very small and the path seems to be unreliable during the 1980s, because the figures could be strongly influenced by temporary minor investments or rounding errors.

(2) Computer equipment in Service sector.

In analysing the pattern of computer equipment investment and tracing the diffusion path of ICT in the service sector, one of the problems is the lack of classifications within the service sector in the early period. Alternatively, the early unobserved pattern is inferred from the comparison of the aggregated pattern with the dis-aggregated one in later periods. The patterns in the service sector are highly volatile in respect of price adjustments, and the interpretation should be cautious.

An early high investment in computer equipment is found in the aggregated services (below, FB&PP&Cr) including Financial Services, Business Services, Public Services, Personal Services and Catering Services. Their detailed investment patterns are observable only from 1984. In the 1979 I/O, the aggregated services (FB&PP&Cr) are separable into three divisions: sub-aggregated services including Financial Services and Business Services (below, FB); sub-aggregated services including Public Services and Personal Services (below, PP); and Catering Services. In the 1984 I/O, Financial services, Business Services, Public Services and Personal Services are separately treated from their sub-aggregated services.

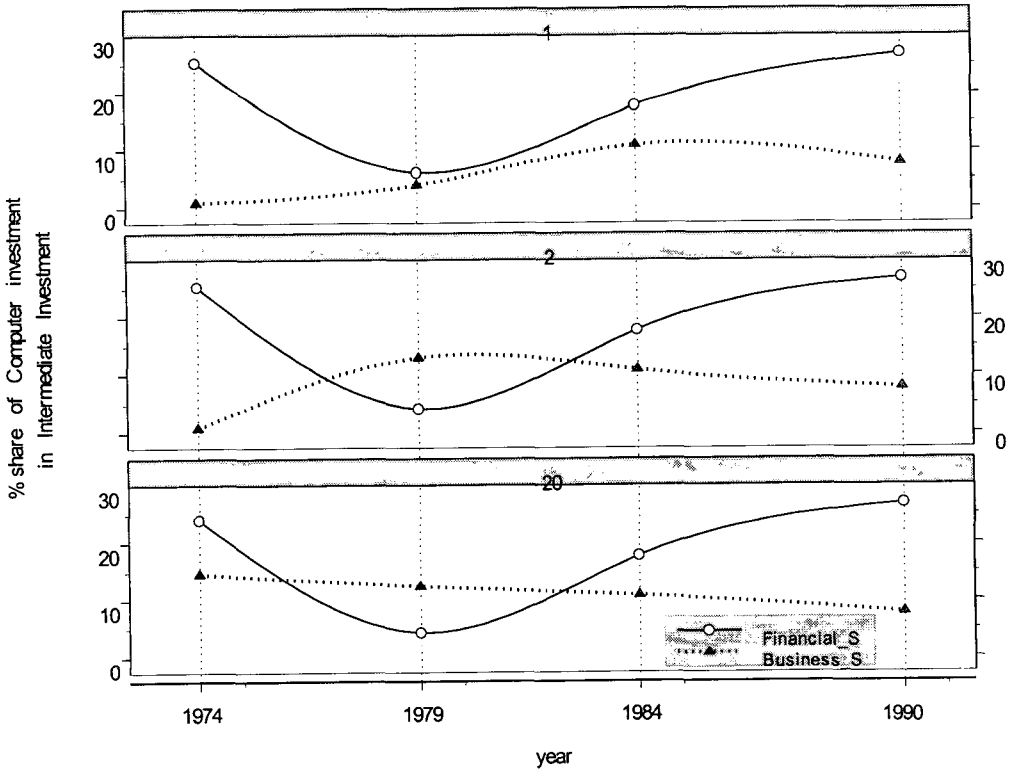
15) For the same reason, Chemical and Oil processing seem to be problematic.

In order to trace the unobserved investment patterns, the different investment shares in Financial Services and Business Services in 1974 and 1979 are simulated under the restriction of observed Computer equipment investment in FB. After tracing each of their Total Intermediate Investments from their relative ratio in later periods and merged Total Intermediate Investment in 1974 and 1979, their patterns of Computer investment are simulated through a different division of Computer investment within them. The simulation is obtained from the share of Computer investment for Business Services within fixed Computer investment in FB.

In Graph 4, the simulated patterns for Financial Services and Business Services show that Financial Services experienced a declining pattern during the late 1970s and re-expanded pattern during the 1980s, regardless of the pattern of Business Services. Therefore, Financial Services is regarded as Type Ⅳ during the 1980s. In the case of Business Services, it is not clear where it can be included. The only clear piece of evidence is the declining pattern in the late 1980s, so they can be included in Type Ⅰ or Type Ⅱ during the 1980s.

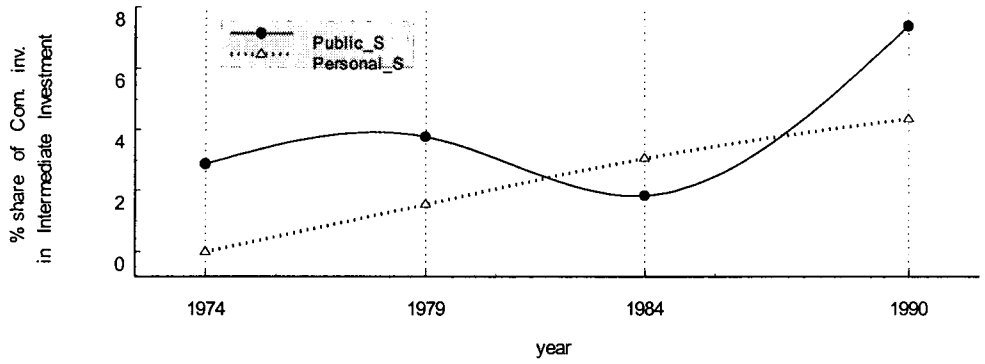
In the same way the pattern of Public Services is also simulated in Graph 5. With the expansion pattern

Graph 4 Investment patterns in Financial Services and Business Services: 1974~1990



Keys: Case '1' : Business Services is Type Ⅰ in the 1980s.
Case '2' : Business Services is Type Ⅱ in the 1980s.
Case '20' : Business Services is Type Ⅱ since the mid 1970s.
Source : Simulation based on each I/O

Graph 5 Investment patterns in Public Services with simulated figures for 1974 and 1979



Source : Simulation based on each I/O.

(Type 0) of Personal Services, Type Ⅲ is suggested for Public Services during the 1980s.

During the early 1990s, most of the service sector seems to move gradually to the third generation of ICT. Computer services show a faster increase than computer equipment except in communication services, which still show a faster increase in computer equipment. Furthermore, Financial Services and Public Services show the declining pattern of the computer equipment share in the unadjusted investment pattern. However, although the rapid expansion of the telecommunication share is expected to be a core element of third generation ICT, the increasing pattern of telecommunication services did not yet arrive until the mid 1990s. The early 1990s seems to be the early expansion stage of third generation ICT in the service sector.

Type Ⅳ : up - up

FB&PP&Cr : steady increasing pattern regardless of price adjustment. With an already relatively high share of computer investment in 1974, it is regarded as Type Ⅳ. FB : up-down pattern (Type I) without the price adjustment but steady increasing pattern (Type Ⅳ) with the price adjustment. Without a possible business cycle effect, the share in 1984 might be lower. With allowing for the business cycle effect, it is regarded as Type Ⅳ. Financial Services : Based on simulation results, it is regarded as Type Ⅳ. Distribution Services : up-down pattern (Type I) without price adjustment, but steady increasing pattern (Type Ⅳ) with price adjustment. With consideration of the business cycle effect, it is regarded as Type Ⅳ.

Type Ⅲ : down - up

PP : down-up pattern regardless of price adjustment. Public Services : Based on simulation results, it is regarded as Type Ⅲ. Catering Services : down-up pattern regardless of price adjustment.

Type I : up - down

Communication Services : up-down pattern

(Type I) without price adjustment but steady increasing pattern (Type Ⅳ) with price adjustment. After removing a business cycle effect, it might remain in Type I due to the relative high differences of the 1984 share compared to 1979 and 1990.

Type 0 : up - up

Personal Services : steady increasing path during 1980s is expected. Transportation Services : up-down pattern (Type I) without price adjustment but steady increasing pattern with price adjustment. With regard to a business cycle effect, it is regarded as a steady increasing pattern. The relatively low figures during the 1970s suggest Type 0 rather than Type Ⅳ.

Unclassified

Business Services : From the simulation results, it seems to be Type I or Type Ⅱ. However, with consideration of a business effect, the classification becomes more complicated. Without further information, a classification is not possible.

4.3. Convergence of telecommunication and computer

Computer service inputs and telecommunications show opposite patterns during the 1990s. As already reported, because of the lack of proper information, there were no available data for the period-industry comparison of the 1980s, prohibiting any examination for the 1980s. Alternatively, the unobserved trend of the 1980s can be inferred from the experience and trend during the 1990s. However, the relevant aspects of the later period cannot be guaranteed to be extensible to the early period, and the inferred trend for the 1980s needs cautious interpretation.

One clue to tracing Computer services and Telecommunication services in ICT expansion is obtainable from their relation to Computer equipment. During the early 1990s, the Computer service input pattern was relatively stable with Computer equipment investment. From the 25-industry classification and with industry output share as industry weights, the correlation between Computer Service Input patterns is relatively stable with Computer Equipment Investment (Figure 2). It remains 0.68 in 1992 and 0.67 in 1995. In the case of Telecommunications, the relation with Computer Equipment Investment increased from 0.45 in 1992 to 0.75 in 1995. If these patterns are extended to the 1980s, it could be suggested that the pattern of computer service is similar to that of computer equipment investment, and that the early relationship between telecommunications and computing is weaker than in the mid-1990s.

Telecommunication services seem to have expanded until the early 1990s and re-expanded since the mid-90s. When it started the re-expansion, the telecommunication share shows some similarity to the pattern of computer service input. The computer service input is relatively stable with computer equipment investment during the early 1990s and shows a fast increasing pattern since then. The increasing importance of software part of ICT input suggests the expansion of the next generation of ICT, which involved the merging of computers and

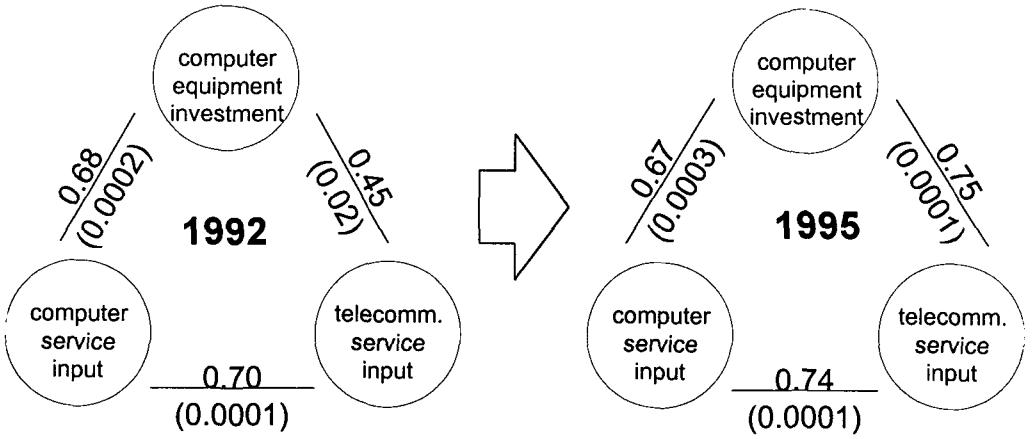


Figure 2 Computer vs. Computer services vs. Telecommunication

Note. Weighted Correlation with size of test inside brackets.
Source: each year's I/O with reclassification for 25 industrial classification.

telecommunications. The role of telecommunications and computer services have become crucial in the diffusion of ICT since the mid 90s compared with the earlier period. However, it should be recalled that much of the service elements are still hidden in the official statistics and the official figures of Computer services are only the tip of the iceberg.

From the detailed examination of the ICT elements, the changed pattern of ICT usage is traced: from mainly Computer equipment base to Computer service and Telecommunication during the mid 1970s to mid 1990s in the UK. It suggests a certain transition from hardware base to software base (not only computer software but also other computer services and telecommunication services etc.). On the other hand, the industrial usage pattern also suggests the increase of using industry. The early usage of ICT is limited in a few industries, but the usage is getting popular in overall industries.

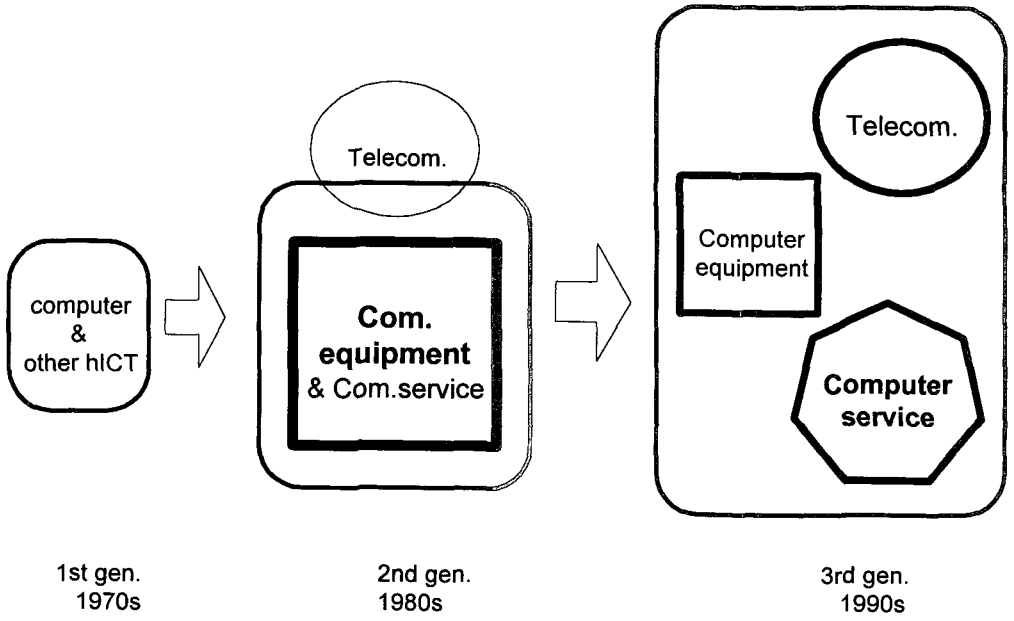
During the early 1990s, the computer service input pattern is relatively stable with computer equipment investment. The correlation remained at 0.68 in 1992 and 0.67 in 1995. In the case of telecommunication, the relation with computer equipment increased from 0.45 in 1992 to 0.75 in 1995.[16] If these patterns are extended to the 1980s, it could be suggested that the pattern of computer service is similar to that of computer equipment investment and that the early relationship between telecommunication and computer is weaker than in the mid-1990s.

5. Concluding remarks

This paper has examined the ICT evolution through the technological changes and usage changes over the

16) The share in the sum of total intermediate input and investment is used with industry output share as a weight. In industry output, joint products are included. The result using normal output share is almost the same.

last 50 years. It shows that the expanding boundary of ICT, from computer equipments and semiconductors and the convergence of computing and communications, to pervasive expansion. has accompanied the development of ICT. From the trajectory of the ICT usage and of the ICT evolution, three generations of ICT have been proposed. Since the emergence of the computer openning the era of ICT, the early computer had attained only limited objectives in limited sectors. The ICT, which is based on this early com-



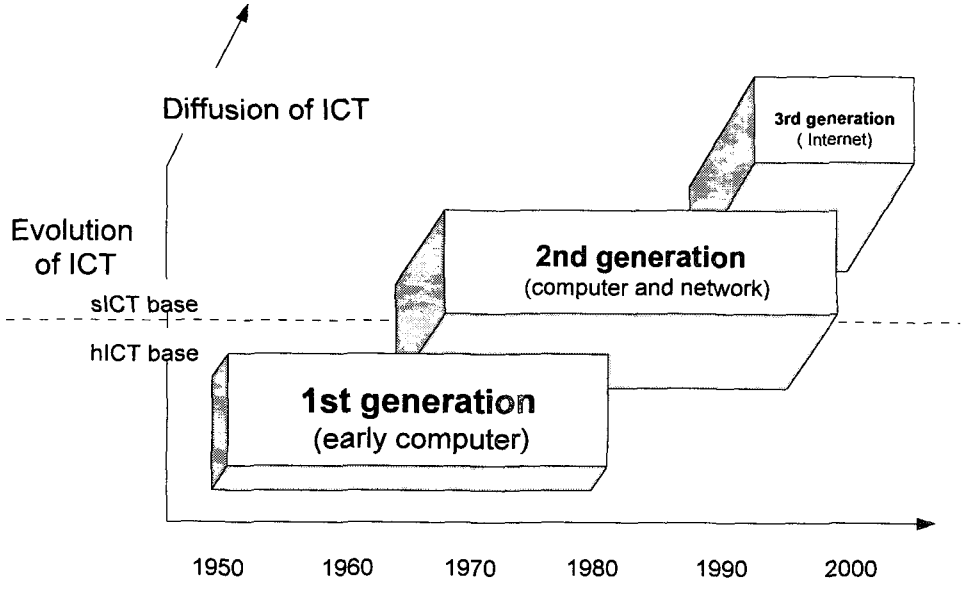


Figure 3 Evolution of ICT

puter, has been regarded above as the 1st generation. The explosion of computers and pre-Internet networks has been regarded as the 2nd generation of ICT. The computer extended its applicability and pervasively diffused to the whole economy, especially during the 1980s. The 3rd generation is regarded above as the real merging process of computers with communications, though already communications were merged with computers during the 2nd generation. Compared to the restricted merging in the 2nd generation, the 3rd generation allows one computer to be connectable to another. Network became a hub of the new generation of ICT. With the explosion of the Internet during the 1990s, the 'ICT' became a common fact of life.

Alongside the expansion of computer networks and the Internets, ICT is becoming a general-purpose technology. With the pervasive expansion of ICT, the user interfaces are crucial and accelerates the expansion of the ICT services. The importance of user interfaces is crucial not only to the benefits and usage of ICT but also to the development of ICT. It requires the development and expansion of ICT services as well as the economic-social system at large.

There are technological interactions between ICT and other fields. In the early 21st century, the pervasive expansion of wireless-Internet and the fusion of ICT and BT/NT would transform social and economic life. Besides developments in the ICT, other important technological changes appear in Biotechnology (BT) and Nanotechnology (NT). Despite differences in their origins, there is a general trend of their convergence or interaction with ICT. The developments in BT and NT depend partly on the convergence with ICT, for instance Bio-informatics is one of the core competences of Biotechnology development. In addition, expected future ICT development is closely related to BT- and/or NT-based hardware development, for instance nano- or quantum- or bio-chips are considered to have the possibility to accelerate ICT development as catalysts in technological development. The expansion of ICT scope brings new ICT-related issues particularly in ICT-based or ICT-delivered services. The development and usage of ICT bring ICT-user problems associated with user activities. Therefore, the ICT interface needs to be mediated by expanding the ICT services, for example management and maintenance of computers and computer-networks, consulting and outsourcing ICT-related issues, etc.

However, changes not only remain in regard to the usage and technological aspects but also radically reshape the routines and structures of individuals, business and government. Still there is a tension between ICT enabling an opening up of new practices and routines, and cases where ICT actually makes existing routines more difficult to alter (Hull, 2000: 155, 157). Also, the increasing importance of networking leads to the important issue of network externalities. The ICT impact on the economy is not solely appropriated by an individual effort but also by collective efforts. Due to the ICT expansion, localized companies and economies could not be separated from the global network economy. Nonetheless, there are still enormous variations, not only in technological developments of

ICT but also in infrastructure, accessibility and personnel proper to the ICT era. The reduced 'ICT-gap' would allow further development of ICT.

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