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ICT Diffusion and Skill Upgrading in Korean Industries

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Abstract

We examine the relationship between the directly observable indicator of new technology, ICT investment ratio, and skill upgrading by analysing changes in employment and wage structure of 25 Korean industrial sectors over the 1993-99 period. The results show that there has been little relationship between ICT diffusion and skill upgrading during the entire period of 1993-99. Meanwhile, the positive relationship was found for the 1996-99 period. Although ICT expenditure and investment have increased sharply since 1993, it appears that the ICT investment has begun to be complementarily combined with skilled labour only since 1997. This explains partly the Bank of Korea's recent finding that the impact of ICT diffusion on productivity was very limited in the 1990s.

Keywords: ICT, skilled workers, skill-biased, technological change, productivity paradox

JEL classification: E2, J2, L6, O1, O3, O5

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1 Introduction

The simultaneous increase of unemployment in developed countries and the rapid diffusion of new technologies represented by ICT (information and communication technology) have led to a revival of academic and policy interest in the nature of the relationship between technological change and employment. The economic debate has focused on the possible 'skill-bias' in recent technological changes. According to the hypothesis of the skill-biased technological change, increases in the growth of the relative demand for high-skilled workers are driven by the diffusion of ICT.

Many economists (Bound and Johnson 1992; Berman, Bound and Griliches 1994; Johnson 1997; and Autor, Katz and Krueger 1998) argue that certain skill-biased technological changes have favoured the employment and wage prospects of skilled workers in the United States. Other economists (Berman, Bound and Machin 1998; Machin and Van Reenen 1998) confirm that a similar pattern is observed in other developed countries, most of these shifts appearing to have occurred within, rather than between, industries.

The ICT diffusion and the skill-biased labour market changes were not the exceptional phenomena of European and North American countries. The Korean economy spent 4.1 per cent of GDP in 1993 and 8.5 per cent of GDP in 1999 on ICT goods. In parallel with the rapid diffusion of ICT and increased expenditure on them, the skill composition of Korean employment experienced dramatic changes.

The share of college graduates or those with more advanced education increased by 12.1 percentage points between 1993 and 1999. During the same period, the share of white-collar employees grew by 8.8 percentage points and that of high-skilled white-collar employees increased by 11.3 percentage points. The wagebill shares of skilled workers showed a trend similar to that observed in the evolution of employment: the wagebill share of college graduates or those with higher educational attainment increased by 12.9 percentage points, and that of white-collar employees and high-skilled white collar employees grew by 9.2 percentage points and 12.7 percentage points, respectively. These simple statistics suggest that the demand for high-skilled workers has been much greater than that for low-skilled workers during the 1990s.

In this paper, we explore the relationship between ICT diffusion and skill upgrading by analysing changes in employment and wage structure of 25 Korean industrial sectors over the 1993-99 period. We examine whether the directly observable indicator of new technology, ICT investment, is associated with the degree of skill upgrading. We define high-skilled workers in four different ways, based on educational level or on an 1-digit level of occupational category as defined by the Korean Standard Classification of Occupations 1992 (KSCO) which is itself based on the International Standard Classification of Occupations 1988.

The paper is composed as follows. Following an introductory section, the second section will examine general trends in skill upgrading in the Korean labour market and ICT diffusion in the Korean economy over the 1993-99 period. Section 3 will investigate, on the one hand, whether most of skill upgrading has occurred within, rather than between, industries. On the other, it will also identify whether there is a positive relationship between ICT diffusion and skill upgrading. The conclusion will be presented in section 4.

The results show that there has been little relationship between ICT diffusion and skill upgrading during the entire period of 1993-99. Meanwhile, a positive relationship was found for the 1996-99 period. Although ICT expenditure and investment have increased sharply since 1993, it appears that the ICT investment has begun to be complementarily combined with skilled labour only since around 1997. This explains partly the Bank of Korea's recent finding that the total factor productivity has not changed significantly despite the ICT diffusion in the 1990s.

2 Evolution of employment, wage, and ICT investment

2.1 Composition of employment and wage

We draw mainly on three data sources to construct the industry-level pooled time series dataset we use in our empirical analysis. The data on value added and capital stock came from the National Statistical Office's 'Mining and Manufacturing Survey'. The total and industry-level ICT investments were estimated from the Bank of Korea's Input-Output Tables. The industry-level labour market data were extracted from the Ministry of Labour's Survey on Wage Structure (SWS) database.

The SWS database enables us to extract wage statistics of non-agricultural sector employees in establishments with at least 10 employees since 1971, together with employment statistics by industry and occupation on a 3-digit level. The classification of industry and occupation categories is coherent during the period of 1993-99. Employment variable used is the number of employees. When we use the SWS dataset, the number of hours worked and the number of employees do not produce significantly different results (Hur and Shin 2001). Wages was defined as the sum of regular and overtime pay, excluding special pay.

Previous studies in other countries about skill upgrading are based on educational composition and non-production employment share. We define high-skilled employment on four different dimensions: highly-educated, non-production, high-skilled white-collar, and relatively high-skilled employment.

Highly-educated workers are defined as employees with college diploma or higher educational attainments. We define non-production workers at 1-digit level of KSCO as those workers belonging to categories 1~5 of KSCO 1992.[1] High-skilled white-collar workers are defined as categories 1~3 of KSCO 1992. Relatively high-skilled employment is the sum of relatively high-skilled workers of both non-production and production workers, defined as those who belong to categories 1~3 and categories 6~8 of the KSCO 1992.

[1] KSCO has been modified five times since it was first introduced in 1963. The fourth amendment KSCO 1992 is based on the UN's International Standard Classification of Occupations 1988 (ISCO 1988) and classifies occupations according to skill level: (1) Legislators, senior officials and managers: any skill level; (2) Professionals: skill level 4 required; (3) Technicians and associate professionals: skill level 3 required; (4) Clerks: skill level 2 required; (5) Service workers and shop and market sales workers: skill level 2 required; (6) Skilled agricultural and fishery workers: skill level 2 required; (7) Craft and related trades workers: skill level 2 required; (8) Plant and machine operators and assemblers: skill level 2 required; and (9) elementary occupations: skill level 1 required.

Table 1 reports the evolution of the proportion of high-skilled workers in aggregate Korean non-agricultural industries from 1993 to 1999. The number of highly-educated, non-production, and high-skilled white-collar workers increased by 12.1 percentage points, 8.8 percentage points, and 11.3 percentage points, respectively, while the number of relatively high-skilled workers increased by 1.3 percentage points over the 1993-99 period. When we divide the observation period into two sub-periods, the employment of high-skilled workers, in particular that of high-skilled white-collar workers, increased more intensively in the last three years of the observation period.

Table 2 describes the general evolution of wagebill shares of high-skilled workers. The wagebill share of highly-educated, non-production, and high-skilled white-collar workers increased by 12.9 percentage points, 9.2 percentage points, and 12.7 percentage points respectively. The wagebill share of relatively high-skilled employment increased by 3.2 percentage points during the same span. We can also confirm that the wagebill shares increased more intensively in the second sub-period.

It is worthy to note that employment shares exceed the increase in wagebill shares during the observation period. However, even if the increase in employment share exceeds the increase in wagebill share during a given period of time, the relative wage of skilled workers does not necessarily increase during the period.

Table 3 shows wage differentials of high-skilled workers for which the trend is decreasing, fluctuating from one period to another. This trend differs from that of other OECD countries where wage inequality has been rising. Increased employment and wagebill shares, and decreased wage differentials suggest that labour supply factors must have not been trivial during the observation period. The supply of skilled workers was large so that they experienced a decrease in their relative wage, and the demand for skilled workers was large in most of sectors so that the wagebill shares of skilled workers did not decrease in the face of relative wage decrease.

Employment shares and wagebill shares of 52 Korean industries are reported in Tables 4 and 5. The first point to note is that they have risen in most of the industries. Let us first analyse the manufacturing sectors. The share of high-skilled white-collar workers increased in all manufacturing industries. The share of highly-educated workers increased in all manufacturing industries except in the automobile industry. The share of non-production workers increased in 19 industries out of 23 manufacturing industries. As for non-manufacturing industries, the share of high-skilled white-collar workers and highly-educated workers increased in 24 out of 29 non-manufacturing industries while the share of non-production workers increased in 19 industries.

Wagebill shares went through a similar evolution. But, on the whole, the wagebill share increase was greater than the employment share increase. Both the employment and wagebill share increase in most of industries suggest that the labour market changes were skill-biased during the observation period. However, the skill-biased labour market changes can result not only from skill-biased technological change but also from other factors such as non-neutral price change of non-labour input (for example, a fall in computer price), increased outsourcing of low skill intensive production processes, an increase in demand for high skill intensive goods, etc). Therefore, additional analyses are necessary to prove if the skill-biased labour market changes have resulted from skill-biased technological change.

Table 1
Employment shares of high-skilled workers
(Unit: %, changes in percentage points)

		Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
1993	All industries	24.9	48.8	20.1	65.9
	Manufacturing	17.9	33.5	13.2	77.5
1996	All industries	30.4	52.3	23.0	64.0
	Manufacturing	21.1	36.1	15.8	75.6
1999	All industries	37.1	57.6	31.4	67.2
	Manufacturing	26.3	39.5	22.4	78.5
Change (percentage points):					
1993-96	All industries	5.5	3.5	2.9	-1.9
	Manufacturing	3.2	2.6	2.6	-1.9
1996-99	All industries	6.6	5.3	8.3	3.2
	Manufacturing	5.2	3.4	6.6	2.9
1993-99	All industries	12.1	8.8	11.3	1.3
	Manufacturing	8.4	6.0	9.2	1.0

Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

Table 2
Wagebill shares of high-skilled workers
(Unit: %, changes in percentage points)

		Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
1993	All industries	32.5	54.9	28.5	69.7
	Manufacturing	23.3	38.8	18.6	77.9
1996	All industries	37.9	58.4	31.2	68.3
	Manufacturing	26.0	41.1	21.2	77.0
1999	All industries	45.4	64.0	41.1	72.9
	Manufacturing	31.6	44.6	28.8	81.0
Change (percentage points):					
1993-96	All industries	5.4	3.5	2.8	-1.4
	Manufacturing	2.7	2.2	2.6	-0.9
1996-99	All industries	7.5	5.6	9.9	4.6
	Manufacturing	5.6	3.5	7.6	4.0
1993-99	All industries	12.9	9.2	12.7	3.2
	Manufacturing	8.3	5.7	10.2	3.1

Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

Table 3
Relative wage of skilled workers (skilled workers' wage/average wage)
(Unit: %, changes in percentage points)

		Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
1993	All industries	130.3	112.6	141.6	105.9
	Manufacturing	130.2	116.0	141.0	100.5
1996	All industries	124.5	111.7	135.6	106.8
	Manufacturing	123.4	113.7	134.1	101.8
1999	All industries	122.4	111.2	131.0	108.6
	Manufacturing	120.1	112.8	128.7	103.1
Change (percentage points):					
1993-96	All industries	-5.8	-0.9	-5.9	0.9
	Manufacturing	-6.8	-2.3	-6.9	1.3
1996-99	All industries	-2.1	-0.5	-4.6	1.8
	Manufacturing	-3.3	-0.9	-5.4	1.4
1993-99	All industries	-7.9	-1.4	-10.5	2.7
	Manufacturing	-10.1	-3.2	-12.3	2.6

Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

Table 4
Changes in employment share, 1993-99
(Unit: percentage points)

Industry	Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
10. Coal mining	2.6	0.9	2.1	-13.2
13. Metal mining	2.0	11.1	4.6	-7.0
14. Other mining	3.4	5.9	4.8	-1.9
15. Food and beverage	6.8	4.5	6.2	-6.6
16. Tobacco	17.6	13.2	12.9	-5.6
17. Textiles	2.9	4.2	6.5	-0.8
18. Wearing apparel	7.5	9.9	7.6	-4.8
19. Leather and footwear	9.8	20.6	15.2	-7.7
20. Wood products	10.7	6.8	6.2	-1.0
21. Pulp and paper	9.9	2.9	7.1	2.3
22. Publishing and printing	8.2	7.0	4.1	-4.8
23. Petroleum products	5.8	-6.7	6.3	13.0
24. Chemical products	10.1	5.2	7.8	0.3
25. Rubber and plastic	4.8	3.4	7.8	1.6
26. Non-metallic mineral	8.4	7.6	11.5	4.0
27. Basic metals	9.5	9.5	11.0	0.7
28. Fabricated metal	8.4	6.4	10.4	2.2
29. Machinery and equipment	8.1	4.5	8.6	4.2
30. Office machinery	17.0	11.7	21.2	10.5
31. Electrical machinery	5.1	-1.1	9.8	10.3
32. Communication equipment	11.7	9.8	11.9	-0.3
33. Precision instruments	15.0	15.2	13.7	-3.0
34. Motor vehicles	-1.1	-3.5	3.4	5.2
35. Other transport equipment	19.7	6.5	11.5	4.9
36. Furniture and other	2.4	-0.9	6.7	3.3
37. Recycling	4.8	8.8	10.2	8.7
40. Electricity and gas	7.1	-13.7	-7.3	2.4
41. Water	-8.4	-15.9	4.5	22.8
45. Construction	10.6	-0.6	7.0	6.6
50. Sales of motor vehicles	5.9	14.4	16.5	2.8
51. Wholesale trade	18.3	7.1	16.7	9.2
52. Retail trade	6.0	-8.8	3.6	11.8
55. Hotel and restaurants	7.1	1.7	4.0	5.4
60. Land transport	-0.1	-2.4	1.3	5.3
61. Water transport	5.4	14.8	7.6	-5.7
62. Air transport	17.3	0.3	17.5	16.4
63. Auxiliary transport activities	18.4	15.1	16.1	-4.8
64. Post and telecommunications	22.3	12.8	15.9	4.4
65. Financial intermediation	16.9	1.7	10.8	10.4
66. Insurance and pension	-4.4	0.8	-8.1	-9.0
67. Auxiliary financial activities	20.1	0.8	29.5	29.0
70. Real estate	-0.7	-10.8	-1.8	4.5
71. Rent and lease	12.0	12.1	-1.0	-17.7
72. Computer	13.4	5.4	14.1	16.5
73. Research and development	5.9	-1.6	2.5	4.5
74. Other business related act.	19.6	15.2	19.4	12.8
80. Education	7.2	3.4	10.6	10.1
85. Health and social work	6.2	0.4	0.5	1.0
90. Sanitation	7.5	7.9	6.9	10.1
91. Membership organizations	13.3	-4.5	6.6	9.2
92. Recreation	-12.3	-16.4	-40.3	-27.8
93. Other service activities	12.3	-17.1	2.6	6.7
Total	12.1	8.7	11.3	1.4

Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

Table 5
Increase in wagebill shares during 1993-2000
(Unit: percentage points)

Industry	Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
10. Coal mining	2.1	0.5	2.1	-14.8
13. Metal mining	3.3	15.0	4.6	-6.9
14. Other mining	4.4	6.0	4.8	-2.2
15. Food and beverage	6.1	4.0	7.2	-2.4
16. Tobacco	17.2	12.8	13.1	-2.3
17. Textiles	2.0	3.3	7.9	2.2
18. Wearing apparel	10.7	12.4	10.8	-3.3
19. Leather and footwear	12.0	26.1	23.9	-3.0
20. Wood products	11.8	6.3	7.0	0.3
21. Pulp and paper	10.0	1.6	10.3	7.0
22. Publishing and printing	11.0	9.6	8.9	-1.4
23. Petroleum products	3.2	-8.2	4.2	12.3
24. Chemical products	8.4	4.0	7.1	2.1
25. Rubber and plastic	4.1	3.0	8.0	3.1
26. Non-metallic mineral	7.4	6.6	11.6	5.2
27. Basic metals	10.5	11.7	13.1	0.7
28. Fabricated metal	9.0	8.1	12.7	3.6
29. Machinery and equipment	6.7	5.1	9.5	4.6
30. Office machinery	18.6	10.9	25.1	15.0
31. Electrical machinery	3.3	-1.9	10.4	11.7
32. Communication equipment	11.6	8.4	11.8	1.9
33. Precision instruments	14.4	15.3	13.8	-2.5
34. Motor vehicles	-3.6	-5.5	2.1	5.7
35. Other transport equipment	22.4	7.7	12.3	4.0
36. Furniture and other	0.9	-2.9	6.5	5.8
37. Recycling	0.7	5.3	11.6	12.5
40. Electricity and gas	6.7	-13.3	-10.1	-0.1
41. Water	-11.1	-23.2	3.7	29.8
45. Construction	10.0	1.0	6.2	4.3
50. Sales of motor vehicles	9.9	16.6	25.2	9.1
51. Wholesale trade	19.7	7.7	17.6	9.6
52. Retail trade	3.4	-8.7	3.7	12.4
55. Hotel and restaurants	8.5	1.8	7.2	8.3
60. Land transport	-0.3	-2.1	0.9	4.1
61. Water transport	1.9	11.7	6.2	-4.2
62. Air transport	11.8	-0.2	17.2	16.3
63. Auxiliary transport activities	23.5	21.5	22.3	0.8
64. Post and telecommunications	24.0	10.6	17.8	8.2
65. Financial intermediation	15.3	1.0	10.4	9.7
66. Insurance and pension	-8.1	0.7	-11.6	-12.4
67. Auxiliary financial activities	16.9	0.8	33.9	33.3
70. Real estate	2.0	-6.0	0.7	6.8
71. Rent and leasing	11.3	13.3	-2.2	-18.0
72. Computer	9.8	2.8	9.4	10.5
73. Research and development	5.8	-1.1	2.6	4.3
74. Other business related act.	22.9	19.3	23.4	15.5
80. Education	5.3	2.1	7.7	7.4
85. Health and social work	5.2	0.6	1.1	1.4
90. Sanitation	6.4	9.4	8.6	6.7
91. Membership organizations	9.2	-4.4	6.3	9.1
92. Recreation	-8.0	-12.7	-31.8	-21.4
93. Other service activities	13.1	-10.5	2.6	3.3
Total	12.9	9.1	12.6	3.2

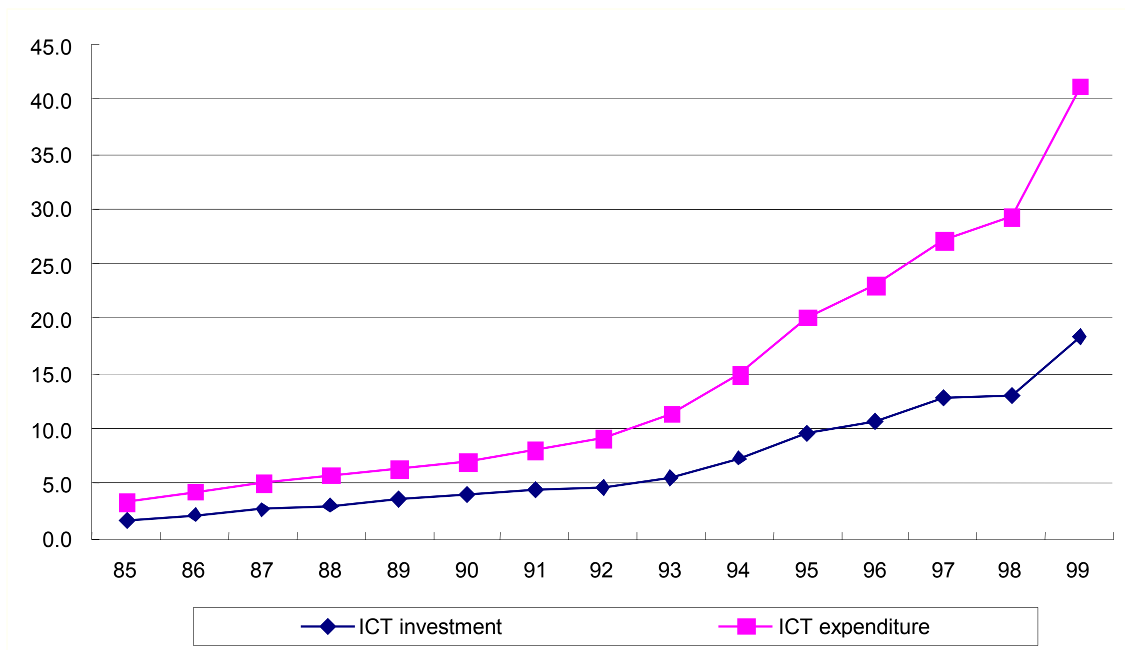
Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

2.2 ICT expenditure and ICT investment

Until recently, ICT expenditure has been defined as expenditure on output or value added of ICT industries. However, it does not correctly measure ICT expenditure in a proper sense. ICT industries included, for example, industries such as the post office while they excluded the industry of telecommunication equipment. The data on ICT expenditure used here are from Lee, Jeong and Kim (2001), where ICT expenditure is defined as the sum of consumption and investment by both private and public sectors in ICT goods and services and estimated from input-output tables. Similarly ICT investment is defined as the sum of private and government investment in ICT goods and services. ICT goods and services were classified based on the methodology of OECD (1999).

Figure 1 describes the evolution of ICT expenditure and investment since 1985. The ICT expenditure increased from 1.2 trillion won in 1980 up to 41.2 trillion won in 1999 (Lee and Jeong 2001; Lee, Jeong and Kim 2001) and its growth rate has accelerated since 1993. The evolution of ICT expenditure as a proportion of GDP is reported in Table 6. Even though the ratio experienced a decrease in the first three years of the 1990s, it has increased continuously since 1993 to reach 8.54 per cent in 1999, superior to the OECD average of 1997 which was 6.9 per cent. The average growth per annum was 0.4 per cent over the 1993-96 period and 1.0 per cent between 1996 and 1999. Table 6 also reports the ratio of ICT investment with respect to GDP, which increased largely in 1995, 1997 and 1999. What is noteworthy here is that ICT investment growth was positive in 1998 despite the South Korean financial crisis at that time while total investment growth was negative.

Figure 1
ICT investment and ICT expenditure
(Unit: trillion won)



Source: Lee and Jeong (2001).

Table 6
ICT investment/GDP and ICT expenditure/GDP
(Unit: billion won, %)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ICT investment	3,969	4,355	4,626	5,455	7,286	9,515	10,624	12,743	13,054	18,364
ICT investment/GDP	2.22	2.01	1.88	1.97	2.25	2.52	2.54	2.81	2.94	3.80
ICT expenditure	6,943	8,045	9,077	11,345	14,872	20,166	23,120	27,131	29,322	41,248
ICT expenditure/GDP	3.88	3.72	3.69	4.09	4.60	5.34	5.52	5.99	6.60	8.54

Source: Lee, Jeong and Kim (2001).

Table 7
ICT investment in volume per real value added, 1993-99

Industry	Average	1993	1996	1999	ICT investment to total ICT investment
10A. Mining	13.0	4.3	11.7	25.6	0.1
15A. Food, beverage and tobacco	1.2	0.6	1.2	2.1	1.3
17. Textiles	0.9	0.5	0.9	1.7	0.4
18A. Wearing apparel and footwear	3.8	1.0	2.9	8.6	0.7
20. Wood products	0.6	0.3	0.5	1.0	0.0
21. Pulp and paper	1.7	0.8	1.6	2.8	0.4
22. Publishing and printing	4.0	1.8	3.4	7.9	1.0
23. Petroleum products	1.1	0.9	1.1	1.6	0.8
24. Chemical products	1.8	1.1	1.7	2.7	2.1
25. Rubber and plastic products	2.6	1.2	2.4	4.4	0.8
26. Non-metallic mineral products	8.0	4.8	6.8	14.3	3.5
27. Basic metals	0.4	0.4	0.4	0.6	0.4
28. Fabricated metal products	2.7	1.4	2.1	5.3	1.1
29. Machinery and equipment	7.4	3.4	5.8	13.5	3.4
30A. Electrical machinery	4.2	3.2	4.7	4.2	8.5
33. Precision instruments	4.5	2.3	3.7	8.9	0.4
34A. Motor vehicles	3.5	2.1	3.4	4.8	5.1
36. Furniture and other	1.8	0.6	1.7	3.2	0.3
40A. Electricity, gas and water	5.5	2.6	5.7	8.4	4.3
50A. Wholesale and retail	1.0	0.6	1.0	1.6	3.7
55. Hotel and restaurants	1.9	0.8	1.8	3.2	1.6
60A. Transport	1.0	0.4	1.0	1.7	1.6
64. Telecommunications	27.8	33.4	26.8	25.8	25.9
65A. Finance, insurance and real estate	2.1	1.1	2.1	3.4	13.6
90A. Other services	8.1	4.1	7.9	13.1	18.9
All industries	4.4	3.0	4.1	6.8	100.0
Manufacturing	3.0	1.7	3.1	6.3	30.3

Note: 1) 10A, 15A, 18A, 30A, 34A, 40A, 50A, 60A, 65A and 90A correspond to 10~14, 15+16, 18+19, 30~32, 34+35, 40+41, 50~52, 60~63, 65~67+70~74, and 80+85+90~92 of KSIC respectively.

2) ICT investment of each industry over total ICT investment is a time mean between 1993 and 1999.

Source: Authors' calculation based on Bank of Korea's Input-Output Tables.

Table 7 shows the ICT investment ratio defined as ICT investment in volume per real value added, together with each industry's ICT investment share over total ICT investment. In most industries, the ICT investment ratio increased more in the second sub-period than in the first sub-period.

3 Empirical analysis of changes in skill composition and ICT investment

To find out what factors explain the employment shift favouring more skilled workers, we implement here empirical analyses in two directions: shift-share analysis, and regression analysis to find any correlation between ICT investment and high-skilled employment.

3.1 Shift-share analysis

Katz and Autor (1999: 1525ff) show that in the special case of a Cobb-Douglas economy, aggregate log relative demand for skilled workers is given by the log relative wagebill of skilled workers and can be decomposed into a between-industry component that depends only on product demand shifts and a within-industry component that depends only on the pace of skill-biased technological change. Thus a decomposition of the growth of the share of aggregate employment (or of the aggregate wagebill) accounted for by skilled workers in the between- and within-industry components can help illustrate the potential importance of skill-biased technological change.

The method of decomposition is the same as was done by Autor, Katz and Krueger (1998) and Machin and Van Reenen (1998). Let N and H denote the total employment and the number of skilled workers, respectively. Then the proportion of skilled employment is:

$$H/N = \sum (H_i/N) = \sum (H_i/N_i)\,(N_i/N).$$

The aggregate change in the skilled proportion $\geq(H/N)$ over a given time period can be decomposed (for industries i=1,…,52) into two components.

$$\Delta(H/N) = \sum \Delta(N_i/N) \cdot (H_i/N_i)^* + \sum \Delta(H_i/N_i) \cdot (N_i/N)^*$$

where (H_i/N_i) is the proportion of skilled workers in industry i and (N_i/N) is the share of total employment in industry i. The asterisk * denotes a time mean. The first term on the right-hand side of the equation is the change in the aggregate proportion of skilled workers attributable to shifts between industries with different proportions of skilled workers. The final term in the expression is the change in the aggregate proportion of skilled workers attributable to changes in the proportion of skilled workers within industries.

Tables 8 and 9 present between- and within-industry decompositions on a 2-digit industry level of the growth in the share of employment and of the wagebill, respectively, accounted for by four definitions of high-skilled workers from 1993 to 1999. The within-industry components of the change in the employment and wagebill explain more than 89.5 per cent of the growth in employment and wagebill in

Table 8
Within- and between-industry decomposition of the increase in the share of high-skilled workers in employment, 1993-99
(Unit: percentage points, %)

		Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
Within	All industries	8.6	3.8	7.9	3.6
		(70.0)	(43.1)	(69.4)	(227.7)
	Manufacturing	7.6	5.4	8.7	1.1
		(90.9)	(91.6)	(93.5)	(91.3)
Between	All industries	3.7	5.0	3.5	-2.0
		(30.0)	(56.9)	(30.6)	(-127.7)
	Manufacturing	0.8	0.5	0.6	0.1
		(9.1)	(8.4)	(6.5)	(8.7)
Total	All industries	12.3	8.8	11.4	1.6
		(100.0)	(100.0)	(100.0)	(100.0)
	Manufacturing	8.4	5.9	9.3	1.2
		(100.0)	(100.0)	(100.0)	(100.0)

Note: The numbers in parentheses are the explained proportion of the total changes.
Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

Table 9
Within- and between-industry decomposition of the increase in the share of high-skilled workers' wagebill, 1993-99
(Unit: percentage points, %)

		Highly-educated	Non-production	High-skilled white-collar	Relatively high-skilled
Within	All industries	8.6	3.9	8.6	4.7
		(65.7)	(43.1)	(67.1)	(134.6)
	Manufacturing	7.4	5.2	9.6	3.1
		(89.5)	(91.8)	(93.6)	(93.2)
Between	All industries	4.5	5.2	4.2	-1.2
		(34.3)	(56.9)	(32.9)	(-34.6)
	Manufacturing	0.9	0.5	0.7	0.2
		(10.5)	(8.2)	(6.4)	(6.8)
Total	All industries	13.1	9.1	12.7	3.5
		(100.0)	(100.0)	(100.0)	(100.0)
	Manufacturing	8.3	5.6	10.3	3.3
		(100.0)	(100.0)	(100.0)	(100.0)

Note: The numbers in parentheses are the explained proportion of the total changes.
Source: Authors' calculation based on Ministry of Labour's *Survey on Wage Structure*.

manufacturing. On the whole industry level, the within-industry components of the change in employment and wagebill explain 65.7~70.0 per cent of the total changes in case of the highly-educated and high-skilled white-collar workers, while 43.1 per cent of the change in employment and wagebill of non-production workers is accounted for by within-industry components.

The shift-share analysis on 2-digit industry level may exaggerate the proportion explained by the within-industry components. However, the analysis above indicates that the impact of skill-biased technological change on relative demand of high-skilled workers was greater than that of product demand shifts across industries. Under some strong assumptions, we can use the shift-share decomposition of the growth of the skilled workers' wagebill share to measure the extent to which growth in the relative demand for skilled workers reflects skill-biased technological change, as opposed to product demand shifts across industries with different skill intensities. However, it does not directly measure the impact of ICT diffusion on the skill-biased labour market changes.

3.2 Regression analysis

We now turn to a regression model to catch the possible impact of ICT diffusion on the change in wagebill shares of high-skilled workers. The estimating equation is a similar one used by Machin and Van Reenen (1998). But we included directly ICT investment ratio (=ICT investment in volume/real value added) instead of R&D/Y (the ratio of the flow of R&D expenditures to value added) in the equation to measure the change in the ICT technology stock. We think that this is a good measure of ICT diffusion and is the main variable we consider in our empirical work.

$$\Delta S_{i,t} = \alpha\Delta\ln(K_{i,t}) + \beta\Delta\ln(Y_{i,t}) + \gamma\,(I_C/Y)_{i,t} + \delta_t D_t + u_{i,t}$$

where

$i = 1,\ldots,25$

$t = 1993,\ldots,1999$

$\Delta S_{i,t}$ = change in the share of skilled worker wage-bill in industry i

$\Delta\ln(K_{i,t})$ = the growth rate of capital stock in industry i

$\Delta\ln(Y_{i,t})$ = the growth rate of real value added in industry i

$(I_C/Y)_{i,t}$ = ICT investment volume over real value added in industry i

D_t = year dummy

$u_{i,t}$ = random error.

The data used are pooled time series data of 25 non-agricultural industries given in Table 7 where 17 are manufacturing industries and the remaining eight are non-manufacturing industries. The deflator used to generate ICT investment in volume is the ICT price index calculated by Lee (2001). The value added and capital stock data were drawn from the Bank of Korea's database.

Table 10 reports regressions of changes in skilled wagebill shares on ICT investment ratio (and year dummies) for each definition of high-skilled workers. In all the equations, the coefficients of the growth of capital stock and the ICT investment ratio are all statistically not significant. And we could not find any evidence of a correlation between change in the relative demand for high-skilled workers and ICT diffusion.

Previous studies attempting to explain the 'productivity paradox' suggest that it would take time before the impact of ICT investment on productivity is detected (OECD 1996;

Seo and Lee 2000). Korean entrepreneurs would say that the introduction of ICT does not lead to a productivity increase instantaneously. When they are asked to set forth reasons for their reluctance to additional ICT investment, they would say that the impact of previous ICT investment on productivity was almost negligible or much less than expected.

Brynjolfsson *et al.* (1991) confirm in their study on firms' organization and ICT that it takes two or three years before ICT investment influences productivity. Meanwhile, Boyer and Caroli (1993), David (1999) and Seo (1999) say that the economic impact of new technology cannot be diffused automatically. According to them, firms' performance can be improved only when the supply of skilled workers is sufficient and the training system to foster skilled workers is well established, because, otherwise, the potential of new technology cannot be achieved even if a new technology is being diffused.

All these evidences, indicating that the impact of ICT diffusion on productivity can be captured with a certain lag, make us also suspect that ICT diffusion can be combined with high-skilled labour several years after ICT investment expansion. The ICT investment in Korea increased largely from 1993, and has accelerated further since 1997 contributing greatly to the recovery of the Korean economy after the financial crisis of 1997. And the employment and wagebill shares increased relatively more in 1996-99 period than in 1993-96 period.

Table 10
Wagebill share of skilled workers and ICT investment:
Pooled time-series analysis

Dependent variable		Estimation method	$\Delta \ln Y$	$\Delta \ln K$	I_C/Y	Adj-R^2	No. of obs
Share of wagebill for workers classified as:	Highly-educated	Random effect model	-0.0003	0.063 *	0.059	0.0742	150
			(0.036)	(0.038)	(0.064)		
		Fixed effect model	0.013	0.066	-0.349	0.0068	
			(0.046)	(0.044)	(0.264)		
	Non-production	Random effect model	-0.054 *	-0.001	0.032	0.0456	150
			(0.032)	(0.035)	(0.059)		
		Fixed effect model	-0.056	-0.011	-0.268	0.0078	
			(0.041)	(0.039)	(0.235)		
	High-skilled white-collar	Random effect model	-0.006	-0.003	0.015	0.0165	150
			(0.030)	(0.032)	(0.054)		
		Fixed effect model	-0.010	-0.012	-0.232	0.0789	
			(0.038)	(0.036)	(0.218)		
	Relatively high-skilled	Random effect model	0.063 **	0.016	-0.017	0.2711	150
			(0.028)	(0.029)	(0.050)		
		Fixed effect model	0.064 *	0.020	0.006	0.2698	
			(0.036)	(0.034)	(0.206)		

Notes: 1) The dependent variables are the annual differences of annual wage-bill shares of high-skilled worker categories. The explanatory variables are the annual differences of real value added, real capital stock, ICT investment ratio. Year dummies were included.

2) ***, ** and * designate respectively significance level of 1%, 5%, 10%.

3) The numbers in parentheses are standard errors.

Table 11
Wage-bill share of skilled workers and ICT investment:
Cross-sectional analysis

Dependent variable		Period	$\Delta \ln Y$	$\Delta \ln K$	I_c/Y	Adj-R^2	No. of obs
Wagebill share of workers classified as:	Highly-educated	1993-96	-0.001	0.061 *	0.281 **	0.4356	25
			(0.034)	(0.031)	(0.112)		
		1996-99	-0.112 **	0.158 ***	0.789 ***	0.5815	
			(0.043)	(0.042)	(0.143)		
	Non-production	1993-96	-0.043	0.057	0.032	-0.0550	25
			(0.048)	(0.044)	(0.159)		
		1996-99	-0.110 **	0.104 **	0.585 ***	0.3786	
			(0.044)	(0.043)	(0.148)		
	High-skilled white-collar	1993-96	0.035	0.016	-0.129	-0.0374	25
			(0.046)	(0.043)	(0.153)		
		1996-99	-0.116 **	0.128 **	1.081 ***	0.5793	
			(0.054)	(0.053)	(0.181)		
	Relatively high-skilled	1993-96	0.080 **	-0.079 **	-0.108	0.1040	25
			(0.038)	(0.035)	(0.127)		
		1996-99	-0.032	0.079	0.476 ***	0.2459	
			(0.048)	(0.048)	(0.162)		

Note: 1) The dependent variables are the three-year difference value of high-skilled workers. The explanatory variables are the three-year differences of real value added, real capital stock, ICT investment ratio.
2) ***, ** and * designate respectively significance level of 1%, 5%, 10%.
3) The numbers in parentheses are standard errors.

We divided the estimating period into two sub-periods and estimated with three-year difference variables. Table 11 reports the results of regression analyses for each category of high-skilled worker definition for two sub-periods.[2] Except for relatively high-skilled workers, we could find a significantly positive coefficient of ICT investment ratio for the second sub-period, implying that ICT diffusion was correlated with the skill-biased labour market changes at least in the 1996-99 period.

In the equation of non-production workers and high-skilled white-collar workers, the coefficient of ICT investment ratio is not significant in the first sub-period while in the equation of highly-educated workers, the coefficients are significant both in the first and the second sub-periods. Huge increases in the supply of college and university graduates in 1990s, due to the reform of the educational system in the 1980s, seem to be related

2 The correlation between ICT investment and skill-biased labour demand does not necessarily imply that ICT investment has caused skill-biased labour market change because relative abundance in high-skilled labour can invoke an increased demand for ICT investment. Table 11 reports the results when the three-year lagged value of ICT investment ratio, $(I_c/Y)_{t-3}$, is used in the regression. When the present value $(I_c/Y)_t$, was used as regressor, the results were similar to what were reported in Table 11. The regression results, which are robust whether the lagged value or the present value of ICT investment ratio is used, let us think that the causality is from ICT investment to skill-biased labour market change. When the dependent variable is Δ (high-skilled labour/total employment), the results were not significantly different from those reported in Table 11.

with the regression result.[3] It would be, then, desirable to adopt a definition of high-skilled workers which takes into consideration occupational characteristics to correctly analyse the skill-biased labour market changes in the 1990s.

Judging from the coefficients of the growth of capital stock being positive and significant in first three equations, technological change embodied in traditional capital seems another source of the skill-biased labour market changes over the second sub-period. Skill-biased technological change associated with capital-deepening is said to be an important driving force behind secular increases in the relative demand for high-skilled workers (Autor, Katz and Krueger 1998). But the evidence is confirmed only over the 1996-99 period.

In the equation for relatively high-skilled workers, a significant impact of ICT investment ratio on relative demand for them is observed. However, the coefficient is far less than that in the equation for high-skilled white-collar workers. Furthermore, it is the least of all the alternative estimation equations. This indicates that ICT diffusion is more related with high-skilled non-production workers than with high-skilled production workers.

Another interesting point we can draw from the regression results is that ICT diffusion has stronger impact on non-production workers (which includes at once high-skilled and low-skilled non-production workers) than on relatively high-skilled workers (which includes high-skilled non-production workers and high-skilled production workers). It seems that ICT diffusion induces more low-skilled non-production workers (clerks, service workers, sale workers) compared to high-skilled production workers (craft and related trades workers; plant, machine operators and assemblers). Rising pressures of competition in the market may have stimulated firms to combine ICT with sales, marketing and after-service workers rather than with operators and assemblers.

The fact that the impact of ICT investment ratio is found only in 1996-99 period may imply that the organizational design and human resource management system of Korean firms are experiencing a fundamental change in the face of ICT diffusion.

Recently, the Bank of Korea (2000) confirmed that ICT diffusion did not seem to have had any significant impact on the total factor productivity of the overall economy and non-ICT industries, even though ICT investment increased from 7.0 per cent of total investment in 1991 to 29.0 per cent in 2000. Boyer and Caroli (1993), David (1999), and Seo (1999) say that the economic impact of new technology, in particular ICT, cannot be diffused automatically, but firms' performance can be improved only when the supply of skilled workers is sufficient and the training system is well established. Otherwise, the potential of new technology cannot be achieved even if a new technology is being diffused.

According to our findings, ICT in Korea began to increase on a large scale since 1993 and started to be combined with skilled workers since 1997. In the earlier stages of ICT diffusion, ICT may have substituted for simple traditional tasks such as data input and data management. But in the late 1990s it may have started to be combined with high-skilled workers as ICT began to be used pervasively in marketing, ERP, e-commerce,

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3 The number of college and university graduates were 215,000 in 1985, 324,000 in 1990, and 473,000 in 2001.

etc. With this reasoning, it would take some more time before the impact of ICT diffusion on the productivity of non-ICT industries and overall economy is apparent.

According to Bresnahan, Brynjolfsson and Hitt (1999), ICT should be combined with a decentralized and human capital-intensive work system before it can lead to high performance of firms. Because ICT investment began to be combined with skilled labour only around 1997, one can conclude that Korean firms have not sufficiently reformed their organizational design and human resource management system to take better advantage of ICT. However, this inference is hypothetical for the moment and will have to be backed up by further investigations on firm-level data.

4 Conclusion

During 1993-99, ICT expenditure and investment increased largely and the skill composition of Korean employment experienced dramatic changes. Most of the skill upgrading has occurred within, rather than between, industries during the observation period. We have investigated whether there is a positive relationship between ICT diffusion and skill upgrading. The main results can be summarized as follows.

First, we could not find any correlation between ICT diffusion and skill upgrading over the whole observation period. However, more ICT investment seems to have been combined with high-skilled workers over the 1996-99 period, implying that the hypothesis of skill-biased technological change can be accepted for this sub-period. It is true for whatever definition of high-skilled workers is used: highly-educated, non-production, high-skilled whitecollar and relatively high-skilled workers. Meanwhile we could not find any significant correlation between ICT diffusion and skill upgrading for the 1993-96 period, except when we used the definition of highly-educated workers as a proxy for high-skilled workers. This is probably due to the increased supply of college and university graduates in the 1990s resulting from the reform of the Korean education system in the 1980s.

More studies would be necessary to understand precisely the reason why the impact of ICT is found to be skill-biased only during the late 1990s. For the moment, we think that the year 1997, when ICT expenditure was around 6 per cent of GDP, was a turning point for the Korean economy in the sense that ICT began to be combined with high-skilled workers. Factors such as the Korean firms' willingness to benchmark American firms which enjoyed high performance with ICT investment and restructuring of organizational design of firms, the huge increase in the supply of college and university graduates together with a relative decrease of their wage, etc. must have stimulated firms to combine ICT with high-skilled workers.

Second, ICT diffusion is more related to high-skilled white-collar workers than to high-skilled production workers.

Third, it seems that ICT diffusion tends to utilize relatively more low-skilled non-production workers (clerks, service workers, sales workers) than high-skilled production workers (craft and related trades workers; plant, machine operators and assemblers). Rising pressures of competition in the market may have stimulated firms to combine

ICT with sales, marketing and after-service workers rather than with operators and assemblers.

Fourth, technological change embodied in non-ICT capital is another source of the skill-biased labour market changes over the 1996-99 period. It is generally believed that skill-biased technological change associated with capital-deepening is an important driving force behind long-run secular increase in the relative demand for high-skilled workers. However, we could find the evidence only for the 1996-99 period. The period 1993-96 seems to call for further studies.

Fifth, the Bank of Korea's finding that total factor productivity has not significantly improved in non-ICT sectors can be explained by the fact that Korean firms have begun to combine ICT with skilled workers only since 1997. If ICT needs to be combined with a decentralized and human capital-intensive work system before it can lead to high performance (Bresnahan, Brynjolfsson and Hitt 1999), the late 1990s may be a transition period for the Korean economy, in the sense that ICT investment began to be combined with skilled labour only around 1997, and Korean firms have only begun to reform their organizational design and human resource management system to take better advantage of new technological changes. However, this inference is hypothetical for the moment and requests further researches using firm-level data.

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