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INFORMATION AND COMMUNICATION TECHNOLOGY DIFFUSION AND SKILL UPGRADING IN KOREAN INDUSTRIES

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We examine the relationship between the directly observable indicator of new technology, information and communication technology (ICT) investment intensity, and skill upgrading by analyzing changes in employment and wage structure of 25 Korean industrial sectors over the 1993–1999 period. The estimation results indicate the following implications. First, although ICT expenditure and investment have increased sharply since 1993, it appears that ICT investment has begun to be complementarily combined with skilled labor only since 1996. Second, our results support the 'limited substitution hypothesis'. ICT has substituted low-skilled non-production workers, whereas the increased demand for high-skilled workers is driven by ICT diffusion in the second sub-period. This asymmetric trend between high-skilled and low-skilled non-production workers in Korea reveals significant differences in comparison with the experiences of other OECD countries. Third, the existence of substitutability between ICT diffusion and low-skilled non-production workers in Korea may cast doubt on the appropriateness of the non-production workers' category, a category regarded as a proxy variable of high-skilled workers in most previous studies.

Keywords: Information and communication technology; Skilled workers; Skill-biased technological change

JEL Classification: J31; L60; O30; O53

1 INTRODUCTION

The simultaneous increase of unemployment in developed countries and the rapid diffusion of new technologies represented by information and communication technology (ICT) 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 skill-biased technological change, increases in the growth of the relative demand for high-skilled workers are driven by the diffusion of ICT.

The skill-biased technological change hypothesis is supported by estimates of equations correlating the employment or wage-bill share of the highly educated (usually those with

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college degree or higher) or non-production workers to the measures of technological change such as R&D expenditures and computer use. Bound and Johnson (1992), Berman *et al.* (1994), Johnson (1997), and Autor *et al.* (1998) argue that certain skill-biased technological changes have favored the employment and wage prospects of skilled workers in the United States. Berman *et al.* (1998) and Machin and Van Reenen (1998) confirm that a similar pattern is observed in other developed countries, with most of these shifts appearing to have occurred within-, rather than between-, industries.

The ICT diffusion and the skill-biased labor market changes were not the exceptional phenomena of the European and North American countries. The Korean economy spent 4.1% of its GDP in 1993 and 8.5% of its GDP in 1999 on ICT goods. In parallel with the rapid diffusion of ICT and the 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 non-production employees grew by 8.8 percentage points, and that of high-skilled non-production employees increased by 11.3 percentage points. The wage-bill shares of skilled workers showed a trend similar to that observed in the evolution of employment: the wage-bill share of college graduates or those with higher educational attainment increased by 12.9 percentage points, and that of non-production 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 investment intensity,[1] which we think is a better measure of ICT progress than R&D expenditures if we want to examine the impact of ICT rather than technology in general, and skill upgrading by analyzing changes in employment and wage structure of 25 Korean industrial sectors over the 1993–1999 period.

We define high-skilled workers in four different ways, on the basis of educational level or on an 1-digit level of occupational category as defined by the *Korean Standard Classification of Occupations 1992*, which is itself based on the *International Standard Classification of Occupations 1988*. By using different measures of high-skilled workers, we intend to analyze how the impact of ICT on the demand for high-skilled workers might differ with respect to the four different measures used. We also aim to identify clearly the specificities of the Korean economy observed in skill upgrading process by contrasting Korean experiences to findings in other countries. Are non-production jobs and highly educated workers equally influenced by ICT diffusion in Korea? Were Korean non-production (or highly educated) workers more influenced by ICT diffusion in comparison with those in other countries?

The paper will proceed as follows. After an introductory section, Section 2 will examine general trends in skill upgrading in the Korean labor market and ICT diffusion in the Korean Economy over the 1993–1999 period. Section 3 will investigate whether most skill upgrading has occurred within-, rather than between-, industries, on the one hand. 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.

[1] Investment ratio is usually defined as the ratio of investment over value added, both in current price. In this study, we use real ICT investment per real value added in the industry-level analysis. We name it 'ICT investment intensity' to distinguish it from investment ratio. Also, given that there is no available hedonic price index in ICT goods in Korea, we calculate the ICT-good price index by selecting and weighting ICT goods from the producer price index released by the Bank of Korea.

2 EVOLUTIONS OF EMPLOYMENT, WAGE, AND ICT INVESTMENT

2.1 Data Used for Analysis

We draw mainly on three data sources to construct the industry-level pooled time-series data set we use in our empirical analysis. The value added and capital stock data were drawn from the Bank of Korea's database. The data on ICT investment used here are from Hur *et al.* (2002a,b), where ICT investment is defined as the sum of private and government investments in ICT goods and services and is estimated from the Bank of Korea's *Input–Output Tables*.[2] The industry-level labor market data were extracted from the Ministry of Labor's *Wage Structure Survey (WSS)* database.

The WSS 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 1993–1999. The number of employees is the employment variable used. When we use the WSS data set, the number of hours worked and the number of employees do not produce significantly different results (Hur and Shin, 2001). Wage is 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 in order to examine the broad evolution of employment of workers with different characteristics: highly educated, non-production, high-skilled non-production, and relatively high-skilled employment. Our classification of high-skilled non-production and relatively high-skilled employment as high-skilled employment is inspired by Colecchina and Papconstantinou (1996) and OECD (1998)[3] who distinguished between high-skilled and low-skilled jobs within the non-production and production worker groups: high-skilled non-production, low-skilled non-production, high-skilled production, and low-skilled production workers.

Highly educated workers in our study are defined as employees with a 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*.[4] High-skilled non-production 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*.

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[2] For the construction of data on ICT investment, see Appendix E.

[3] The study by OECD (1998), based on this classification of skill categories, revealed significant differences between countries both in the importance of the four occupational groups and in their contribution to overall employment growth in the 1990s. High-skilled non-production jobs have been the main occupational category underlying employment growth in Canada, France, Australia, and New Zealand, whereas in the United States, Germany and Italy the contribution of low-skilled non-production jobs has been greater.

[4] *Korean Standard Classification of Occupations* (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.
9. Elementary occupations: skill-level 1 required.

TABLE I Changes in employment shares, relative wages and wage-bill shares (Unit: percentage points, %).

Period		*Highly educated*	*Non-production*	*High-skilled non-production*	*Relatively high-skilled*
	Changes in employment shares of high-skilled workers (100 × annual log changes)				
1993–1996	All industries	6.7	2.3	4.5	−1.0
Changes	Manufacturing	5.5	2.5	6.0	−0.8
1996–1999	All industries	6.6	3.2	10.4	1.6
Changes	Manufacturing	7.3	3.0	11.6	1.3
1993–1999	All industries	6.6	2.8	7.4	0.3
Changes	Manufacturing	6.4	2.7	8.8	0.2
	Changes in relative wages of high-skilled workers (high-skilled workers' wage/average wage) (100 × annual log changes)				
1993–1996	All industries	−1.5	−0.3	−1.4	0.3
Changes	Manufacturing	−1.8	−0.7	−1.7	0.4
1996–1999	All industries	−0.6	−0.1	−1.2	0.6
Changes	Manufacturing	−0.9	−0.3	−1.4	0.4
1993–1999	All industries	−1.0	−0.2	−1.3	0.4
Changes	Manufacturing	−1.3	−0.5	−1.5	0.4
	Changes in wage-bill shares of high-skilled workers = (changes in employment shares of high-skilled workers + changes in relative wage of high-skilled workers)				
1993–1996	All industries	5.2	2.0	3.0	−0.7
Changes	Manufacturing	3.7	1.8	4.3	−0.4
1996–1999	All industries	6.1	3.1	9.2	2.2
Changes	Manufacturing	6.4	2.7	10.3	1.7
1993–1999	All industries	5.6	2.6	6.1	0.7
Changes	Manufacturing	5.1	2.3	7.3	0.6

Source: Authors' calculation based on Ministry of Labor's WSS.

2.2 General Trends of Employment and Wage

Table I reports the annual changes in the employment shares, relative wages, and wage-bill shares of high-skilled workers in aggregate Korean non-agricultural industries from 1993 to 1999. The number of highly educated, non-production, and high-skilled non-production workers increased by 6.6%, 2.8%, and 7.4% per year, respectively, whereas the number of relatively high-skilled workers increased by 0.3% over the 1993–1999 period. When we divide the observation period into two sub-periods, the employment of high-skilled workers, in particular that of high-skilled non-production workers, increased more rapidly in the last 3 years of the observation period.

Table I also describes the general evolution of wage-bill shares of high-skilled workers.[5] The wage-bill share of highly educated, non-production, and high-skilled non-production workers increased annually by 5.6%, 2.6%, and 6.1%, respectively. We can also confirm that the wage-bill shares increased more intensively in the second sub-period.

However, the trends of wage differentials of high-skilled workers indicated in Table I are decreasing (with exception of relatively high-skilled category) in spite of their steady increase in the employment shares. This trend differs from that of the United States where wage inequality has been rising since the 1980s (Tab. II). A large increase in the supply of college graduates in the late 1960s and 1970s first depressed the college premium in the United States, but was followed by a large increase in the premium in the 1980s due to the excess demand for highly educated workers. However, during the period 1970–1996, the share of Korean

[5] In defining the wage-bill shares, it could be total cost or total wage. Due to the assumption that only labor is the variable input while capital is quasi-fixed input, the only cost involved is labor cost. We bisect labor into high-skilled and low-skilled workers. Wage-bill shares of high/low-skilled workers is the high/low-skilled wage-bill per total cost (wage).

TABLE II Annual growth rates of college premium, relative supply, and relative demand of college workers ($\sigma = 1.4$) (unit: percentage points, %).

	United States			*Korea*		
Period	*Relative wage*	*Relative supply change*	*Relative demand change*	*Relative wage*	*Relative supply change*	*Relative demand change*
1970–1980	−0.74	4.30	3.26	0.65	2.58	3.49
1980–1990	1.51	2.48	4.60	−4.24	7.17	1.23
1990–1996	0.40	2.35	2.91	−3.06	5.95	1.67

Source: US data from Autor *et al.* (1998) based on the Current Population Surveys. Data for Korea from Serrano and Timmer (2002). Σ represents the aggregate elasticity of substitution between college and high school equivalents.

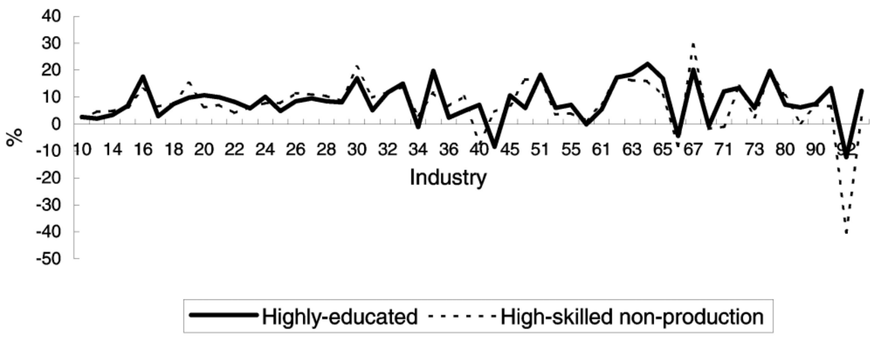

FIGURE 1 Changes in employment shares of highly educated workers and high-skilled non-production workers, 1993–1999 (unit: percentage points, %). *Note*: For the definition of industries, see Appendix A.

college-educated workers in the labor force increased 5.2% annually, an increase much higher than in the United States. At the same time, the college premium in Korea showed a steady decline for the period 1980–1996 due to the excess supply of the college graduates.

Figure 1 describes the evolution of employment shares of highly educated and high-skilled non-production workers for 52 Korean industries from 1993 to 1999. These two groups of high-skilled workers reveal the similar increasing trends in employment shares in most industries, implying that highly educated workers must have been employed in the high-skilled non-production jobs such as senior officials, managers, professionals, technicians, and associate professionals.

Figure 3 and Table III show the changes in employment shares of low-skilled non-production workers, which are the subset of non-production workers. During the period 1993–1999, the share of low-skilled non-production workers in the labor force decreased in most industries, which was much higher in the service sector than in manufacturing sector. This decreasing trend of low-skilled non-production workers is contrasted with the increase in the high-skilled non-production workers as is shown in Figures 1 and 3. The noticeable decrease of low-skilled non-production jobs in the service sector seems to have resulted in a sharp decline of employment share of non-production workers in this sector in spite of the increase of high-skilled non-production employment (Figs. 1–3). This stylized fact differs from that of other developed countries such as the United States, Canada, Japan, Germany, France, Australia, and Italy, where both low-skilled non-production and high-skilled non-production jobs simultaneously increased in the 1980s and 1990s (OECD, 1998 and see Fig. 4). Most industries also saw a decrease in the employment share of high-skilled production jobs, with a much higher

TABLE III Changes in employment shares, 1993–1999 (unit: percentage points, %).

Year		*HE*	*NP*	*HSNP*	*LSNP*	*P*	*HSP*	*LSP*	*RHS*
1993	All industries	24.9	48.8	20.1	28.7	51.2	45.8	5.4	65.9
	Manufacturing	17.9	33.5	13.2	20.3	66.5	64.3	2.2	77.5
1996	All industries	30.4	52.3	23	29.3	47.7	41	6.7	64
	Manufacturing	21.1	36.1	15.8	20.3	63.9	59.8	4.1	75.6
1999	All industries	37.1	57.6	31.4	26.2	42.4	35.8	6.6	67.2
	Manufacturing	26.3	39.5	22.4	17.1	60.5	56.1	4.4	78.5

Note: HE denotes highly educated workers; NP, non-production workers; HSNP, high-skilled non-production workers; LSNP, low-skilled non-production workers; P, production workers; HSP, high-skilled production workers; LSP, low-skilled production workers; RHS, relatively high-skilled workers.
Source: Authors' calculation based on Ministry of Labor's WSS.

decrease in manufacturing sectors such as apparel, leather and footwear, office machinery, communication equipment, and precision instruments (Fig. 5).

2.3 ICT Expenditure and ICT Investment

Figure 6 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, and its growth rate has accelerated since 1993. The evolution of ICT expenditure as a proportion of GDP is reported in Table IV. Even though the ratio experienced a decrease in the first 3 years

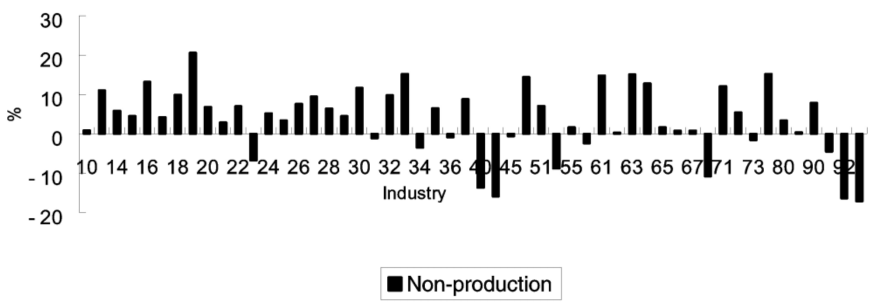

FIGURE 2 Changes in employment shares of non-production workers, 1993–1999 (unit: percentage points, %). *Note*: For the definition of industries, see Appendix A.

FIGURE 3 Changes in employment shares of low-skilled non-production workers, 1993–1999 (unit: percentage points, %). *Note*: For the definition of industries, see Appendix A.

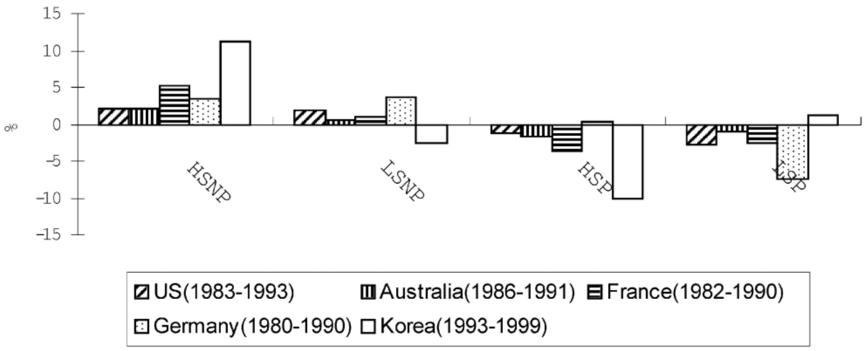

FIGURE 4 International comparison of changes in employment shares (unit: percentage points, %). *Note*: HSNP denotes high-skilled non-production workers; LSNP, low-skilled non-production workers; HSP, high-skilled production workers; LSP, low-skilled production workers. *Source*: The data except for Korea are based on OECD (1998). The data for Korea are authors' calculation based on Ministry of Labor's WSS.

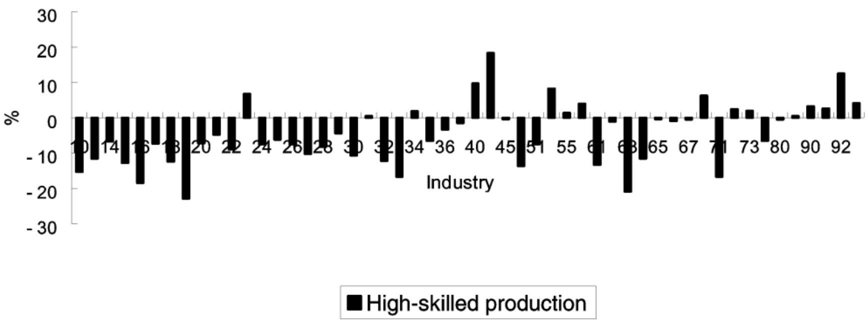

FIGURE 5 Changes in employment shares of high-skilled production workers, 1993–1999 (unit: percentage points, %). *Note*: For the definition of industries, see Appendix A.

of the 1990s, it increased continuously since 1993 to reach 8.54% in 1999, superior to the OECD average of 1997, which was 6.9% . The average growth per annum was 0.4% over the 1993–1996 period and 1.0% between 1996 and 1999. Table IV 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, a time during which total investment growth was negative.

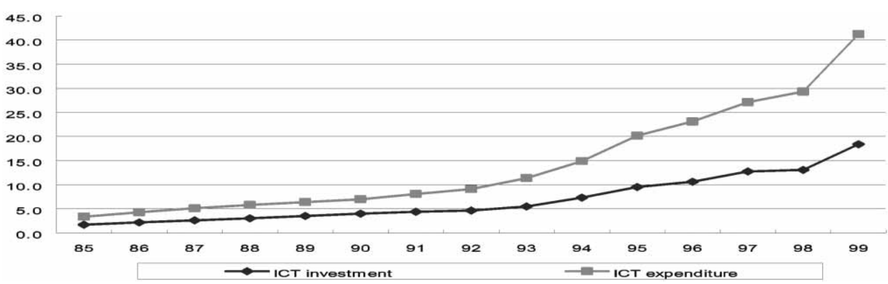

FIGURE 6 ICT investment and ICT expenditure (unit: trillion won). *Source*: Authors' calculation based on Bank of Korea's Input–Output Tables.

TABLE IV ICT investment/GDP and ICT expenditure/GDP, 1990–1999 (unit: billion won and %).

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

3 EMPIRICAL ANALYSIS OF CHANGES IN SKILL COMPOSITION AND ICT INVESTMENT

To find out what factors explain the employment shift favoring 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) show that in the special case of a Cobb–Douglas economy, aggregate log relative demand for skilled workers is given by the log relative wage-bill of skilled workers. This aggregate log relative demand 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 wage-bill) accounted for by skilled workers into between- and within-industry components can help illustrate the potential importance of skill-biased technological change.

The method of decomposition here is the same as was done by Autor *et al.* (1998) and Machin and Van Reenen (1998). Let N and H denote the total employment and the number of skilled workers, respectively. The proportion of skilled employment is thus

$$\frac{H}{N} = \sum \left(\frac{H_i}{N}\right) = \sum \left(\frac{H_i}{N_i}\right)\left(\frac{N_i}{N}\right).$$

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

$$\Delta\left(\frac{H}{N}\right) = \sum \Delta\left(\frac{N_i}{N}\right)\cdot\left(\frac{H_i}{N_i}\right)^* + \sum \Delta\left(\frac{H_i}{N_i}\right)\cdot\left(\frac{N_i}{N}\right)^*,$$

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 $*$ 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 V and VI present between- and within-industry decompositions on a 2-digit industry level of the growth in the share of employment and of the wage-bill, 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 wage-bill explain $>89.5\%$ of the growth in employment and wage-bill in manufacturing.

TABLE V Within- and between-industry decomposition of the increase in the share of high-skilled workers in employment, 1993–1999 (unit: percentage points, %).

		Highly educated		*Non-production*	*High-skilled non-production*	*Relatively high-skilled*
		United States	*Korea*	*(Korea)*	*(Korea)*	*(Korea)*
Within	All industries	109	70.0	43.1	69.4	227.7
	Manufacturing	111	90.9	91.6	93.5	91.3
Between	All industries	−9	30.0	56.9	30.6	−127.7
	Manufacturing	−11	9.1	8.4	6.5	8.7
Total	All industries	100	100.0	100.0	100.0	100.0
	Manufacturing	100	100.0	100.0	100.0	100.0

Source: US data (1990–1996) from Autor *et al.* (1998) based on the Current Population Surveys. Data for Korea from authors' calculation based on Ministry of Labor's WSS.

However, on the whole industry level, the shares of increase in the demand for skills attributed to between- and within-industry effects vary with definitions of high-skilled workers. The within-industry components of the change in employment and wage-bill explain 65.7–70.0% of the total changes in cases of the highly educated and high-skilled non-production workers, whereas 43.1% of the change in employment and wage-bill of non-production workers is accounted for by within-industry components. This is a different result than those observed by Autor *et al.* (1998) and Machine and Van Reenen (1998) for the United States and OECD countries, respectively. In the United States and other OECD countries, within-industry changes account for most of the overall changes even when high-skilled workers are defined as non-production workers.

The relatively low share of within-industry component in the case of Korean non-production workers is related to their decline in the employment share in service sectors (Fig. 2). In particular, low-skilled non-production workers, the subset of non-production workers, have experienced a sharp decrease in employment share in most service sectors. For example, the decrease of employment share of low-skilled non-production workers outweighs the increasing trends of high-skilled non-production workers' employment share in sectors such as water, construction, retail trade, land transport, research and development, membership organization, and other service sectors (see Fig. 3). Therefore, the dominance of between-industry change

TABLE VI Within- and between-industry decomposition of the increase in the share of high-skilled workers' wage-bill, 1993–1999 (unit: percentage points, %).

		Highly educated		*Non-production*	*High-skilled non-production*	*Relatively high-skilled*
		United States	*Korea*	*(Korea)*	*(Korea)*	*(Korea)*
Within	All industries	92	65.7	43.1	67.1	134.6
	Manufacturing	102	89.5	91.8	93.6	93.2
Between	All industries	8	34.3	56.9	32.9	−34.6
	Manufacturing	−2	10.5	8.2	6.4	6.8
Total	All industries	100	100.0	100.0	100.0	100.0
	Manufacturing	100	100.0	100.0	100.0	100.0

Source: US data (1990–1996) from Autor *et al.* (1998) based on the Current Population Surveys. Data for Korea from authors' calculation based on Ministry of Labor's WSS.

in comparison with the within-industry components in the case of non-production workers might be attributed to the sharp drop of employment shares of low-skilled non-production workers.

The shift-share analysis on the 2-digit industry level may exaggerate the proportion explained by the within-industry components. However, the analysis mentioned above indicates that the impact of skill-biased technological change on the relative demand of high-skilled workers was greater than that of product demand shifts across industries, at least for highly educated and high-skilled non-production categories. Under some strong assumptions, we can use the shift-share decomposition of the growth of the skilled workers' wage-bill share to measure the extent to which the 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 labor 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 wage-bill shares of high-skilled workers. The estimating equation is a similar one used by Machin and Van Reenen (1998),[6] but we included ICT investment intensity instead of R&D expenditures over value added in the equation to measure the changes in ICT. We think that this is a better measure of ICT progress than R&D expenditures if we want to examine the impact of ICT rather than technology in general.

$$\Delta S_{i,t} = \alpha \Delta \ln(K_{i,t}) + \beta \Delta \ln(Y_{i,t}) + \gamma \left(\frac{I_C}{Y}\right)_{i,t} + \delta_t D_t + u_{i,t} \tag{1}$$

where $i = 1, \ldots, 25$, $t = 1993, \ldots, 1999$, $\Delta S_{i,t}$ is the change in the share of skilled worker wage-bill in industry i, $\Delta \ln(K_{i,t})$ is the growth rate of capital stock in industry i, $\Delta \ln(Y_{i,t})$ is the growth rate of real value added in industry i, $(I_C/Y)_{i,t}$ is the ICT investment volume over real value added in industry i, D_t is the year dummy, and $u_{i,t}$ is the random error.

The data used are pooled time-series data of 25 non-agricultural industries given in the Appendices. Seventeen 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.

Tables VII and VIII report regressions of changes in wage-bill shares on the ICT investment intensity (and year dummies) for each definition of workers. In all the equations, the coefficients of the growth of capital stock and ICT investment intensity are all statistically not significant, and we could not find any evidence of 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, 2000; Seo and Lee, 2000). Korean entrepreneurs would say that the introduction of ICT does not lead to an instantaneous increase in productivity. 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 negligible or much less than expected.

Brynjolfsson *et al.* (1991) confirm in their study on firms' organization and ICT that it takes 2 or 3 years before ICT investment influences productivity. Meanwhile, Boyer and Caroli

[6] For more details about the derivation of estimated equation, see Denny and Pinto (1978), and Machin and Van Reenen (1998).

TABLE VII Wage-bill share of skilled workers and ICT investment: pooled time-series analysis.

Dependent variable	*Estimation method*	Δ *ln Y*	Δ *ln K*	I_C/Y	$Adj\text{-}R^2$	*No. of observations*
Wage-bill share of highly educated workers	Random effect model	−0.0003 (0.036)	0.063 (0.038)	0.059 (0.064)	0.0742	150
	Fixed effect model	0.013 (0.046)	0.066 (0.044)	−0.349 (0.264)	0.0068	
Wage-bill share of non-production workers	Random effect model	−0.054* (0.032)	−0.001 (0.035)	0.032 (0.059)	0.0456	150
	Fixed effect model	−0.056 (0.041)	−0.011 (0.039)	−0.268 (0.235)	0.0078	
Wage-bill share of high-skilled non-production workers	Random effect model	−0.006 (0.030)	−0.003 (0.032)	0.015 (0.054)	0.0165	150
	Fixed effect model	−0.010 (0.038)	−0.012 (0.036)	−0.232 (0.218)	0.0789	
Wage-bill share of relatively-high-skilled workers	Random effect model	0.063** (0.028)	−0.016 (0.029)	−0.017 (0.050)	0.2711	150
	Fixed effect model	0.064* (0.036)	0.020 (0.034)	0.006 (0.206)	0.2698	

Note: The dependent variables are the annual differences of annual wage-bill shares. The explanatory variables are the annual differences of real value added, real capital stock, ICT investment intensity. Year dummies were included. The numbers in parentheses are standard errors.
***, **, and * designate, respectively, significance level of 1%, 5%, and 10%.

(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.

TABLE VIII Wage-bill share of other three categories and ICT investment: pooled time-series analysis.

Dependent variable	*Estimation method*	Δ *ln Y*	Δ *ln K*	I_C/Y	$Adj\text{-}R^2$	*No. of observations*
Wage-bill share of low-skilled non-production workers	Random effect model	−0.037* (0.021)	−0.003 (0.023)	0.011 (0.039)	0.3218	150
	Fixed effect model	−0.033 (0.027)	−0.002 (0.027)	−0.021 (0.159)	0.3222	
Wage-bill share of high-skilled production workers	Random effect model	−0.070** (0.036)	0.016 (0.035)	−0.039 (0.067)	0.0676	150
	Fixed effect model	0.073 (0.047)	0.029 (0.046)	0.230 (0.274)	0.0760	
Wage-bill share of low-skilled production workers	Random effect model	0.090** (0.045)	0.000 (0.049)	−0.049 (0.083)	0.1423	150
	Fixed effect model	0.085 (0.059)	0.010 (0.056)	0.279 (0.336)	0.1494	

Note: The dependent variables are the annual differences of annual wage-bill shares. The explanatory variables are the annual differences of real value added, real capital stock, ICT investment intensity. Year dummies were included. The numbers in parentheses are standard errors.
***, **, and * designate, respectively, significance level of 1%, 5%, and 10%.

TABLE IX Wage-bill share of skilled workers and ICT investment: cross-sectional analysis.

Dependent variable	*Period*	Δ *ln Y*	Δ *ln K*	I_C/Y	$Adj\text{-}R^2$	*No. of observations*
Wage-bill share of highly educated workers	1993–1995	0.0253 (0.0266)	0.0693** (0.0288)	−0.0281 (0.0775)	0.3467	25
	1996–1999	−0.112** (0.043)	0.158*** (0.042)	0.789*** (0.143)	0.5815	
Wage-bill share of non-production workers	1993–1995	0.0084 (0.0353)	0.0249 (0.0381)	−0.0087 (0.1024)	0.0791	25
	1996–1999	−0.110** (0.044)	0.104** (0.043)	0.585*** (0.148)	0.3786	
Wage-bill share of high-skilled non-production workers	1993–1995	0.0154 (0.0332)	0.0228 (0.0359)	0.0155 (0.0964)	0.0378	25
	1996–1999	−0.116** (0.054)	0.128** (0.053)	1.081*** (0.181)	0.5793	
Wage-bill share of relatively high-skilled workers	1993–1995	0.0389 (0.0265)	−0.0542* (0.0287)	0.0358 (0.0771)	0.0396	25
	1996–1999	−0.032 (0.048)	0.079 (0.048)	0.476*** (0.162)	0.2459	

Note: The dependent and explanatory variables are the 2-year difference values for the first sub-period and the 3-year difference values for the second sub-period. The numbers in parentheses are standard errors.
***, **, and * designate, respectively, significance level of 1%, 5%, and 10%.

All this evidence, indicating that the impact of ICT diffusion on productivity can be caught with a certain lag, make us also suspect that ICT diffusion can be combined with high-skilled labor several years after ICT investment expansion. ICT investment in Korea increased largely from 1993, and it has accelerated further since 1997 contributing greatly to the recovery of the Korean economy after the financial crisis of 1997.

To test whether there is a structural break during the period of analysis, we tested the possibility of structural change for each of skill definition by checking the statistical significance of year dummy variables adding to explanatory variables (see Appendix D). We found evidence of structural change starting from 1996 for the cases of high-skilled non-production workers, relatively high-skilled workers, low-skilled non-production workers, and low-skilled production workers. Following these results, we divided the estimating period into two sub-periods (1993–1995 and 1996–1999).[7]

Table IX reports the results of regression analyses for each definition of high-skilled workers for two sub-periods. In the first three definitions of high-skilled workers, the coefficients of ICT investment intensity are not significant in the first sub-period, whereas we could find a significantly positive coefficient of ICT investment intensity for the second sub-period, implying that ICT diffusion was correlated with the skill-biased labor market changes, at least in the 1996–1999 period.

High-skilled non-production workers showed the highest elasticity *vis-à-vis* ICT diffusion in Korea, which is expected from Table I.

In the equation for relatively high-skilled workers, a significant impact of ICT investment intensity on relative demand for them is found. However, the coefficient is far less than that

[7] We obtain similar results when we alternatively split the time-span into a pre- and post-crisis period.

TABLE X Wage-bill share of other three categories and ICT investment: cross-sectional analysis.

Dependent variable	*Period*	Δ *ln Y*	Δ *ln K*	I_C/Y	$Adj\text{-}R^2$	*No. of observations*
Wage-bill share of low-skilled non-production workers	1993–1995	−0.0070 (0.0278)	0.0021 (0.0300)	−0.0242 (0.0807)	0.1219	25
	1996–1999	0.1786 (0.04577)	−0.0263 (0.0458)	−0.5066*** (0.1558)	0.3429	
Wage-bill share of high-skilled production workers	1993–1995	0.0235 (0.0382)	−0.0770* (0.0413)	0.0203 (0.1110)	0.0362	25
	1996–1999	0.0895** (0.0432)	−0.0487 (0.0432)	−0.6083*** (0.1471)	0.4418	
Wage-bill share of low-high production workers	1993–1995	−0.0014 (0.0541)	−0.0271 (0.0585)	0.0330 (0.1572)	0.1183	25
	1996–1999	0.0937 (0.0706)	−0.0765 (0.0707)	−0.0798 (0.2405)	−0.0426	

Note: The dependent and explanatory variables are the 2-year difference values for the first sub-period and the 3-year difference values for the second sub-period. The numbers in parentheses are standard errors.
***, **, and * designate, respectively, significance level of 1%, 5%, and 10%.

in the equation for high-skilled non-production workers. Furthermore, it is the least of all the alternative estimation equations, implying that ICT diffusion is more related with high-skilled non-production workers than with high-skilled production workers.

Table X reports the results of regression analyses for the other three categories of complementary groups for two sub-periods. None of the coefficients of ICT investment intensity are significant in the first sub-period, whereas we could find the significantly negative coefficients of ICT investment intensity for the second sub-period in the case of low-skilled non-production workers and high-skilled production workers. This implies that ICT diffusion was correlated with the substitution of the above two worker groups (categories 4–8 of KSCO 1992) at least in the 1996–1999 period. These estimation results are coherent with Figures 3 and 5, which show the decline of employment shares of low-skilled white collar and high-skilled production workers.

As was predicted by the 'limited substitution hypothesis' of Bresnahan (1999), ICT substituted low-skilled white-collar workers (clerks, service workers, sale workers) and high-skilled blue-collar workers (craft and trade related workers; plant, machine operators and assemblers), whereas the demand for high-skilled workers was driven by ICT diffusion in the second sub-period. Many of routine white- and blue-collar jobs were standardized and automated, and consequently the demand for modestly skilled white- and blue-collar workers was lowered. However, more complex and human-capital-intensive jobs, such as managers, professionals, and technical workers, proved remarkably difficult to be substituted by ICT.

This asymmetric trend between high-skilled and low-skilled non-production workers in Korea reveals significant difference in comparison with the experiences of other OECD countries (OECD, 1998). Both high-skilled and low-skilled non-production jobs have been the main occupational categories underlying employment growth in Canada, France, Australia, New Zealand, the United States, Germany, and Italy during the 1980s and through the early 1990s (see Fig. 4). As the above-mentioned explanation about the decomposition of changes in employment suggests (see Tabs. V and VI), the low share of within-industry component in the case of non-production workers is related to the substitution of low-skilled non-production workers by ICT.

According to our findings, ICT in Korea began to increase on a large scale in 1993 and started to be combined with skilled workers in 1996. In the late 1990s, ICT may have substituted simple traditional tasks such as data input and data management, whereas it may have started to be combined with high-skilled workers as ICT began to be used pervasively in marketing, ERP, e-commerce, etc.

4 CONCLUSION

During the period 1993–1999, 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 1996–1999 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 non-production, and relatively high-skilled workers. Meanwhile, we could not find any significant correlation between ICT diffusion and skill upgrading for the 1993–1995 period. 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 1996 or 1997, when ICT expenditure explained around 6% of GDP, was a turning point for the Korean economy in the sense that the ICT began to be combined with high-skilled workers. Korean firms' willingness to benchmark American firms that enjoyed high performance with ICT investment and restructuring of organizational design of firms, a huge increase in the supply of Korean 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, our regression results support the limited substitution hypothesis proposed by Bresnahan (1999). ICT has substituted low-skilled non-production workers (clerks, service workers, sale workers) and high-skilled production workers (craft and trade related workers; plant, machine operators and assemblers), whereas the demand increase for high-skilled workers is driven by ICT diffusion in the second sub-period. Much of the routine work of both white- and blue-collar jobs has been standardized and industrialized, and consequently the demand for modestly skilled white- and blue-collar workers has been lowered. However, complex and human-capital-intensive work, such as that of managers, professionals, and technical workers, has proved difficult to be automated with ICT. This asymmetric trend between high-skilled and low-skilled non-production workers in Korea reveals significant differences in comparison with the experiences of other OECD countries.

Third, the existence of substitutability between ICT diffusion and low-skilled non-production workers in Korea may cast doubt on the appropriateness of regarding the non-production workers' category as a proxy variable of high-skilled workers in most previous studies.

Fourth, 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 began to combine ICT with skilled workers only since the late 1990s. If ICT must be combined with a decentralized and human-capital-intensive work system before it can lead to high performance

(Bresnahan *et al.* 2002), the late 1990s may be thought of as a transition period for the Korean economy in the sense that it was then that ICT investment began to be combined with skilled labor, and then that Korean firms began 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 calls for further research using firm-level data.

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APPENDIX A: CHANGES IN EMPLOYMENT SHARES, 1993–1999

Industry	*Highly educated*	*Non-production*	*High-skilled non-production*	*Low-skilled white collar*	*High-skilled blue collar*	*Relatively high-skilled*
10. Coal mining	2.6	0.9	2.1	−1.2	−15.3	−13.2
13. Metal mining	2.0	11.1	4.6	6.5	−11.6	−7.0
14. Other mining	3.4	5.9	4.8	1.1	−6.7	−1.9
15. Food and beverage	6.8	4.5	6.2	−1.7	−12.8	−6.6
16. Tobacco	17.6	13.2	12.9	0.3	−18.5	−5.6
17. Textiles	2.9	4.2	6.5	−2.3	−7.3	−0.8
18. Wearing apparel	7.5	9.9	7.6	2.3	−12.4	−4.8
19. Leather and footwear	9.8	20.6	15.2	5.4	−22.9	−7.7
20. Wood products	10.7	6.8	6.2	0.6	−7.2	−1.0
21. Pulp and paper	9.9	2.9	7.1	−4.2	−4.8	2.3
22. Publishing and printing	8.2	7.0	4.1	2.9	−8.9	−4.8
23. Petroleum products	5.8	−6.7	6.3	−13	6.7	13.0
24. Chemical products	10.1	5.2	7.8	−2.6	−7.5	0.3
25. Rubber and plastic	4.8	3.4	7.8	−4.4	−6.2	1.6
26. Non-metallic mineral	8.4	7.6	11.5	−3.9	−7.5	4.0
27. Basic metals	9.5	9.5	11.0	−1.5	−10.3	0.7
28. Fabricated metal	8.4	6.4	10.4	−4	−8.2	2.2
29. Machinery and equipment	8.1	4.5	8.6	−4.1	−4.4	4.2
30. Office machinery	17.0	11.7	21.2	−9.5	−10.7	10.5
31. Electrical machinery	5.1	−1.1	9.8	−10.9	0.5	10.3
32. Communication equipment	11.7	9.8	11.9	−2.1	−12.2	−0.3
33. Precision instruments	15.0	15.2	13.7	1.5	−16.7	−3.0
34. Motor vehicles	−1.1	−3.5	3.4	−6.9	1.8	5.2
35. Other transport equipment	19.7	6.5	11.5	−5	−6.6	4.9
36. Furniture and other	2.4	−0.9	6.7	−7.6	−3.4	3.3
37. Recycling	4.8	8.8	10.2	−1.4	−1.5	8.7
40. Electricity and gas	7.1	−13.7	−7.3	−6.4	9.7	2.4
41. Water	−8.4	−15.9	4.5	−20.4	18.3	22.8
45. Construction	10.6	−0.6	7.0	−7.6	−0.4	6.6
50. Sales of motor vehicles	5.9	14.4	16.5	−2.1	−13.7	2.8
51. Wholesale trade	18.3	7.1	16.7	−9.6	−7.5	9.2
52. Retail trade	6.0	−8.8	3.6	−12.4	8.2	11.8
55. Hotel and restaurants	7.1	1.7	4.0	−2.3	1.4	5.4
60. Land transport	−0.1	−2.4	1.3	−3.7	4	5.3
61. Water transport	5.4	14.8	7.6	7.2	−13.3	−5.7
62. Air transport	17.3	0.3	17.5	−17.2	−1.1	16.4
63. Auxiliary transport activities	18.4	15.1	16.1	−1	−20.9	−4.8
64. Post and telecommunications	22.3	12.8	15.9	−3.1	−11.5	4.4
65. Financial intermediation	16.9	1.7	10.8	−9.1	−0.4	10.4
66. Insurance and pension	−4.4	0.8	−8.1	8.9	−0.9	−9.0
67. Auxiliary financial activities	20.1	0.8	29.5	−28.7	−0.5	29.0
70. Real estate	−0.7	−10.8	−1.8	−9	6.3	4.5
71. Rent and lease	12.0	12.1	−1.0	13.1	−16.7	−17.7
72. Computer	13.4	5.4	14.1	−8.7	2.4	16.5
73. Research and development	5.9	−1.6	2.5	−4.1	2	4.5
74. Other business related activities	19.6	15.2	19.4	−4.2	−6.6	12.8
80. Education	7.2	3.4	10.6	−7.2	−0.5	10.1
85. Health and social work	6.2	0.4	0.5	−0.1	0.5	1.0
90. Sanitation	7.5	7.9	6.9	1	3.2	10.1
91. Membership organizations	13.3	−4.5	6.6	−11.1	2.6	9.2
92. Recreation	−12.3	−16.4	−40.3	23.9	12.5	−27.8
93. Other service activities	12.3	−17.1	2.6	−19.7	4.1	6.7
Total	12.1	8.7	11.3	−2.6	−9.9	1.4

Unit: Percentage points, %.
Source: Authors' calculation based on Ministry of Labor's WSS.

APPENDIX B: INCREASE IN WAGE-BILL SHARES, 1993–1999

Industry	*Highly educated*	*Non-production*	*High-skilled non-production*	*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 lease	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 activities	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

Unit: Percent points, %.

Source: Authors' calculation based on Ministry of Labor's WSS.

APPENDIX C: ICT INVESTMENT INTENSITY, 1993–1999

Industry	*1993–1999 Average*	*1993*	*1996*	*1999*	*ICT Investment/ total ICT Investment*
10A. Mining	0.8	0.5	0.7	1.6	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	3.3
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	3.7
30A. Electrical machinery	4.2	3.2	4.7	4.2	9.0
33. Precision instruments	4.5	2.3	3.7	8.9	0.4
34A. Motor vehicles	3.5	2.1	3.4	4.8	5.2
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	4.6
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	1.7
60A. Transport	1.0	0.4	1.0	1.7	1.7
64. Telecommunications	27.8	33.4	26.8	25.8	23.6
65A. Fin., ins. and real estate	2.1	1.1	2.1	3.4	14.1
90A. Other services	8.1	4.1	7.9	13.1	19.5
All industries	3.2	2.2	3.5	5.4	100.0
Manufacturing	2.9	1.6	2.8	4.2	30.3

Unit: Percentage points, %.
Note: 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. 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.

APPENDIX D: RESULTS OF STRUCTURAL CHANGE TESTS

Dependent variable	*Estimation method*	*1995*	*1996*	*1997*
Wage-bill share of highly educated workers	Random effect model	0	0	0
Wage-bill share of non-production workers	Random effect model	0	0	0
Wage-bill share of high-skilled non-production workers	Random effect model	0	**	***
Wage-bill share of relatively-high-skilled workers	Random effect model	0	***	***
Wage-bill share of low-skilled non-production workers	Random effect model	0	***	***
Wage-bill share of high-skilled production workers	Random effect model	0	0	0
Wage-bill share of low-skilled production workers	Random effect model	0	**	**

Note: Estimation equation: $\Delta S_{i,t} = a\Delta \ln(K_{i,t}) + \beta\Delta \ln(Y_{i,t}) + \gamma(I_C/Y)_{i,t} + \delta_t D_t + \varepsilon\Delta \ln(K_{i,t}) \cdot D_t + \phi\Delta \ln(Y_{i,t}) \cdot D_t + \varphi(I_C/Y)_{i,t} \cdot D_t + u_{i,t}$. The dependent and explanatory variables are the 2-year difference values. Null Hypothesis: H_0: $\delta, \varepsilon, \phi, \varphi = 0$ $***$, $**$, and $*$ signify-respectively, that the null hypotheses are rejected at the significance level of 1%, 5% and 10%. 0 Signifies that the null hypothesis is accepted. We obtain similar results when the dependent and explanatory variables are the 3-year difference values.

APPENDIX E: THE CONSTRUCTION OF DATA FOR THE ICT INVESTMENT

We take ICT as the information infrastructure concept and define ICT investment as the expenditure on goods and services that need to construct information infrastructure and digitalize the social information. We started from the input–output table to estimate ICT expenditure and investment. Input–output tables refer to matrix-type statistical tables that record all transactions related to production and disposal of goods, and services between each industrial sector within a certain region during a certain period according to a certain principle and formula. Horizontally, it shows the allocation of consumption of goods and services, whereas vertically it indicates the input structure to produce goods and services. Out of 402 basic sectors in input–output tables in 1990, 1995, and 1998, we first choose seven ICT sectors, which can be broadly divided into ICT manufacturing and ICT service sector; the ICT service sector includes broadcasting, telecommunication and computer related service industries, whereas the ICT manufacturing sector is the collection of ICT related equipment producing industries. ICT expenditure comprises the summation of private consumption expenditure, government consumption expenditure, and gross private and government fixed capital formation in the input–output table. Also, subtracting private consumption expenditure from ICT expenditure provides ICT investment. Using the input–output table, we have ICT expenditure and investment in 1990, 1995, and 1998, when the Bank of Korea released the input–output table. However, the problem is that no such data is available for other periods. Therefore, in this paper, we fill the missing periods by estimating the ICT investment as following. First, we use the industrial production index released by the Korea National Statistical Office to estimate domestic productions in each sectors. We forecast the period 1991–1994 by multiplying the corresponding industrial production index from 1990 input–output tables. Similarly, we determine the values for 1996–1997 from 1995 input–output tables. Next, we calculate the ratio of each item to domestic production in the 1990, 1995, and 1998 input–output tables. Assuming the linear change in each computed ratio for the unreported periods 1991–1994 and 1996–1997, we approximate the ratios for those years. For example, we compute the ratio of government consumption expenditure to domestic production in 1990, 1995, and 1998. We linearly interpolate the ratio of government consumption expenditure to domestic production for unreported periods. Lastly, by multiplying the estimated domestic production and ratio for each item, we obtain the estimated values of government consumption expenditure, and gross private and government fixed capital formation for unreported periods. Adding them together, we acquire the determined ICT investment. ICT investment in 1999 is determined in a similar way. However, the ratio of each item to domestic production is assumed to be the same as that for 1998. We use the data for the period 1993–1999 to match the other data set.