Technical Change, Heterogeneity in Skill Demand, and Employment Polarization

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We explore how the rapid adoption of computer-related assets affects the recent polarization of employment in the U.S. labor market, which is inconsistent with the skill-biased technological change hypothesis. Similar to Goos and Manning (2007), we show that the job polarization could be explained by the routinization hypothesis of Autor, Levy, and Murnane (2003). Our empirical analyses confirm that the newly adopted computer-related capitals change the demands for three types of skilled workers heterogeneously, leading to a polarization in employment structure.

Keywords: Computerization, Skill Demand, Polarization

JEL Classification: J21, J24, O30

I. Introduction

In the 1990s, the employment patterns in the U.S. labor market changed dramatically. During the period 1979-1989, employment growth has monotonically increased in terms of occupation rank: the share of employment below the median occupation declined, whereas the employment share above the median occupation increased. The monotonic pattern, however, has changed toward a certain polarized structure in occupational employment growth after that period (Autor 2010).

Autor, Levey and Murnane (2003) and Autor, Katz and Kearney (2006)

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show that a polarized employment structure exists in the recent U.S. labor market, characterized by the fastest growth of high-skilled jobs, the slowest growth of middle-skilled jobs, and the moderate growth of low-skilled jobs. Specifically, the authors explore how the employment growth measured based on changes in shares of occupations has changed against initial occupational skill in the United States. These measurements demonstrate that the employment growth in the 1980s has monotonically increased with skill distribution as opposed to the employment growth in the 1990s, which presents a polarized pattern of employment.

Before this polarized employment structure in the U.S. labor market emerged in recent years, much research in the literature focused on the effects of technological change on the labor market (Acemoglu 1999; Acemoglu 2002; Allen 2001; Autor, Katz and Kearney; Berman, Bound and Machin 1998; Card and DiNardo 2002; Kim and Min 2006). In particular, the effects of technological change on the labor market (*e.g.*, wage inequality or structural change of employment) have been explained primarily by skill-biased technological change (SBTC). This implies a bias in favor of skilled workers or more educated workers against unskilled workers. Many studies show positive correlations between the capital intensity based on the newly advanced technology and skilled workers (Berman, Bound and Grilliches 1994; Goldin and Katz 1996; Johnson 1997; Levy and Murnane 1996; Machin and Reenen 1998), thus supporting the SBTC hypothesis.

The recent patterns of polarized employment growth, however, significantly differ from the SBTC hypothesis of monotonic shifts in skill demand from a lower skill distribution toward a higher distribution. That is, these monotonic patterns are compatible no longer with the polarized structural changes of employment in the U.S. labor market. Thus, more effective models are required to analyze these new patterns in the labor market. In this regard, Autor *et al.* (2003) provide a simple theory to explain how changes in employment structure are related to advances in computer-related technology, claiming that investments in computerization would be the rationale behind the structural changes in polarized employment.

With the questions of what computers do in the workplace, what tasks they would perform efficiently, and whether they complement or substitute for human labor inputs, Autor *et al.* (2003, 2006) argue that computer-related assets would displace workers in carrying out the tasks which can be performed by well-programmed rules or specific manuals (what they call routine tasks), and complement workers in conducting nonroutine tasks such as problem-solving jobs or abstract tasks.

Specifically, a decline in the price of computer-based capitals has led to a decrease in the wages of middle-skilled workers for routine tasks relative to high-skilled workers and low-skilled workers for nonroutine cognitive tasks and nonroutine manual tasks, respectively. Given that computer-related assets dealing with routine tasks increase the marginal productivity of skilled workers for nonroutine tasks, the relative wage paid to nonroutine tasks notably rises as the price of computerization declines. Therefore, some marginal workers who have performed previously in routine tasks would reallocate their labor supplies toward either nonroutine cognitive tasks or nonroutine manual tasks. These self-selections facilitated by advances in computer-related technology increase the employment of high-skilled workers for nonroutine cognitive tasks and that of low-skilled workers for nonroutine manual tasks. Consequently, an increase in investment in computer-related assets that replace human labor inputs for routine tasks caused the employment structure to change toward increasing employments of high- and low-skilled workers, which exhibits a polarized pattern.

With the routinization hypothesis of Autor *et al.* (2003), we examine how computer-related technology would heterogeneously affect the employment of workers in tasks: nonroutine cognitive, routine, and nonroutine manual tasks at the industry level. Aside from the effect of heterogeneity in skill level on employment, we show how the differences across industries in terms of investing in computer-related assets would facilitate changes in the employment of each type of skilled workers.

The remainder of this paper is organized as follows: Section II describes data sources for computerization and skill demand measurement as well as introduces some recent stylized facts on job polarization in the U.S. labor market. Although Autor *et al.* (2003, 2006) use the measurements of tasks by job to analyze the changes in tasks within industry, educational group, and occupation, we adopt educational credentials of workers performing their jobs (*i.e.*, high-, middle-, and low-skilled workers) as measurements of four types of different tasks: nonroutine cognitive, routine (routine cognitive and routine manual), and nonroutine manual.

Given that the occupations for nonroutine cognitive tasks and nonroutine manual tasks are likely to be at the top and bottom of wage distribution respectively, and the occupations for routine tasks are intensively distributed in the middle wage (Goos and Manning 2007), it would be justified to analyze different types of tasks by measuring educational attainment. Moreover, in place of the extent of computer use or other measurements in previous studies (Autor, Katz, and Krueger 1998; Autor *et al.* 2003), we measure computerization by directly using three types of capital investments: computing equipment, software, and communication equipment from the EU KLEMS database.

Section III documents empirical models and results. This section tests whether the effects of computerization on demands for high-, middle-, and low-skilled workers are consistent with the theoretical predictions from the routinization hypothesis using a simple specification, including a period dummy. Using the period dummy is one of the simplest approaches to capture the effects of computer diffusion on employment structure.[1] In the second part of Section III, we consider the industrial differences in the adoption of computerization, and focus on comparing the effects of computerization on skill demands for three types of industry groups: the heavily computerized, the modestly invested, and the isolated from computerization. Section IV concludes by summarizing our findings.

II. Data and Preliminary Results

A. Data

In this paper, we use data from the EU KLEMS Growth and Productivity Accounts for the computerization measurement, employment share, and wage bill share of three types of skilled workers from 1970 to 2005.[2] The industry classification from the EU KLEMS database (US SIC and NAICS) is segmentalized into 31 classifications. We employ the real gross fixed capital formation as a variable of computerization, which is measured by a total of computing equipment, software, and communication equipment for information and communication technology using 1995 as a base year. On the other hand, the capital stock we use in the analysis is measured based on the total of real fixed capital stock for all assets in the base year.

The three types of skilled workers, high-, middle-, and low-skilled workers, are defined as those with a bachelor's degree(s), those with

[1] As will be described later, we use a period dummy of 1 indicating post-1995. In practice, many previous studies have shown the computerization in the United States has grown explosively since 1995. In this context, our approach in this paper differs from that of Michaels *et al.* (2010), who simply analyzed the effects of computerization on the employment growth over the period 1980-2004 for 11 countries without controlling for the prevalence of computers.

[2] See Chun, Pyo, and Rhee (2008) for details.

TABLE 1
DESCRIPTIVE STATISTICS FOR EU KLEMS GROWTH AND PRODUCTIVITY: 1970-2005

Variables	Obs.	Mean	Std. Dev.	Min	Max
Year	1,116	1987.5	10.393	1970	2005
Industry	1,116	16	8.948	1	31
High-skilled Employment Share	1,116	20.879	13.113	2.812	69.018
Middle-skilled Employment share	1,116	60.784	9.323	28.586	82.654
Low-skilled Employment Share	1,116	18.337	12.034	1.308	61.531
High-skilled Wage Share	1,116	29.298	16.739	4.568	79.058
Middle-skilled Wage share	1,116	55.916	11.222	17.876	79.462
Low-skilled Wage Share	1,116	14.787	11.322	0.716	55.879
Log ICT Equipment	1,116	7.138	2.221	0.676	12.538
Log Real Value Added	1,116	11.888	1.123	7.219	14.663
Log Capital Stock	1,116	12.321	1.228	10.008	16.265

Notes: The number of observations is in thousands, and all the share variables, in percentages. ICT equipment, real value added, and capital stock are all in millions of U.S. dollars.

less than 16 years of schooling, and those with less than 12 years of schooling, respectively. The share of employment for these three types of skilled workers is measured based on a fraction of each type of employed workers in total employment. The share of wage bill is measured by a fraction of labor compensation for each type of skilled worker in total labor compensation. Finally, gross value added is deflated at constant prices at the base year.

B. Preliminary Results

a) Patterns of Share Level

Table 2 shows the share levels of three types of skilled workers over the selected years 1970, 1980, 1990, 2000 and 2005, along with annual average percent changes in share over the periods 1970-1990 and 1990-2005. Over the selected years, the shares of high-skilled workers have increased, whereas those of the low-skilled have decreased. However, an

TABLE 2
SHARE LEVELS FOR THREE TYPES OF WORKERS AND COMPUTERIZATION OVER 1970-2005

Variables	1970	1980	1990	2000	2005	1970-1990	1990-2005
HS Employment	12.888	20.169	25.838	29.041	31.657	12.950	5.819
HS Wage Share	20.449	27.770	37.567	44.378	48.102	17.118	10.535
MS Employment	52.277	60.686	61.630	60.382	58.488	9.353	-3.142
MS Wage Share	51.000	57.015	53.923	49.848	47.002	2.922	-6.921
LS Employment	34.835	19.145	12.532	10.576	9.856	-22.303	-2.677
LS Wage Share	28.551	15.215	8.511	5.773	4.897	-20.041	-3.614
Log ICT	9.600	10.610	11.693	13.559	13.896	2.094	2.203

Notes: All the share variables are in percentages. Note that the figures over the two periods 1970-1990 and 1990-2005 are annual average percent changes in percentage points.

increasing pattern in the employment share of middle-skilled workers after the 1980s has changed to a decreasing pattern since the 1990s.

At the seventh and eighth columns of Table 2, the annual average percent changes in share over the periods 1970-1990 and 1990-2005 show heterogeneous patterns by type of skilled workers. Though the annual average increase in the share of high-skilled workers declined over the second period, compared to the first period in both employment and wage bill, an increase in the share of the high-skilled workers has continued throughout the whole period. Meanwhile, the annual average increase in the share of middle-skilled workers over the first period has changed to a decrease over the second period. This result enables us to conjecture a possibility of substitution for middle-skilled workers by computerization.

It is of significance to examine changes in the share of low-skilled workers over two periods. Over the first period, the share of low-skilled workers in both employment and wage bill has declined sharply. However, it is noticeable that the decrease in the share of low-skilled workers has moderated by approximately 20 percentage points over the second period. These facts are all consistent with the predictions by Autor *et al.* (2003). In addition, these polarized patterns in the U.S. labor market could be observed in all industries. Figures 1 through 5 present annualized changes in the employment share of three types of skilled workers by industry over the period 1980-2005. We can observe from these figures that there are the patterns of job polarization over skill distribution in all the industries, except for the transport equipment industry, although utilities, retail trade, post and communications, finance, and hotels have different trends of timing in job polarization.

b) Shift-Share Decomposition

To examine the factors that can explain rapid shifts in demand of workers among the hypotheses in the literature (*e.g.*, trade, deindustrialization, and the skill-biased technological change), Autor *et al.* (1998) adopt shift-share analysis. An investigation into whether shifts in demand of skilled workers occur within a specific industry or between industries would enable us to identify which hypothesis holds. Although we do not aim to investigate which factor is the most important to a structural change in employment in this paper, it would be of use to decompose the shifts in demand for three different types of skilled workers, leading to confirm the changes in employment share toward the polarized structure in the recent labor market. A standard decomposition of changes in share of three types of skilled workers into two components (*i.e.*, shifts in demand between industries and changes in skill demand within a specific industry) follows:

$$\Delta S_{jt} = \Sigma_k \Delta S_{kt}\, \theta_{jk} + \Sigma_k \Delta \theta_{jkt}\, S_k, \tag{1}$$

$$\Delta S_{jt} = \Delta S^B_{kt} + \Delta S^W_{kt}, \tag{2}$$

where S_{jkt} is the employment share of a task j in industry k at time t, ΔS_{kt} implies a change in share of industry k over a period of time, $(t_1 - t_0)$, and S_k indicates an average share of industry k over the period, $S_k = (S_{kt_0} + S_{kt_1})/2$. $\Delta \theta_{jkt}$ is a change in share of task j in industry k over the period, $(t_1 - t_0)$, and θ_{jk}, an average share of task j in industry k over the period, given by $\theta_{jk} = (\theta_{jkt_0} + \theta_{jkt_1})/2$. That is, a change in overall share of task j, ΔS_{jt}, would be decomposed into two components: a shift in demand between industries, ΔS^B_{kt}, and a shift within a specific industry, ΔS^W_{kt}.

In Table 3, we show the results of shift-share analysis by task, decomposing shifts in total demand of skilled workers into shifts in demand among industries or within an industry in terms of employment and wage bill. The upper panel shows the shifts in demand for nonroutine cognitive tasks, equivalent to high-skilled workers; the middle panel, for routine cognitive and routine manual tasks, pertaining to middle-skilled workers; and the lower panel, for nonroutine manual tasks, equivalent to low-skilled workers. In addition, we include in each panel a set of

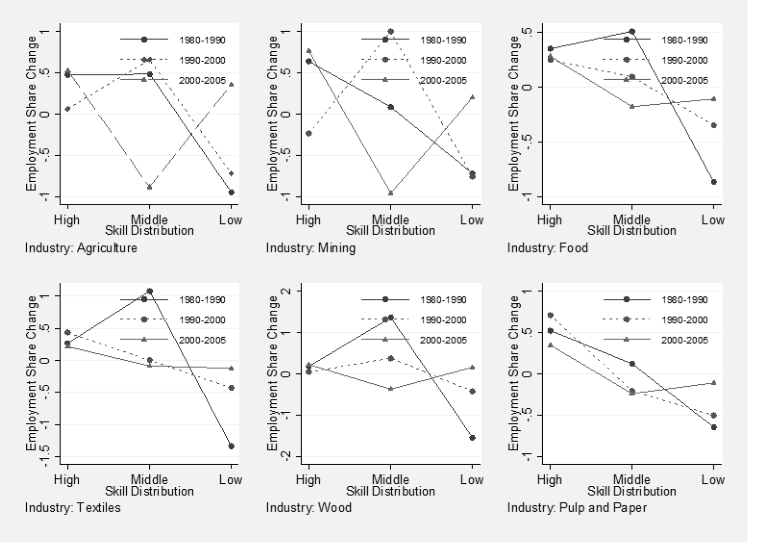

FIGURE 1

ANNUAL CHANGE IN EMPLOYMENT SHARE

BY TYPE OF SKILLED WORKERS FOR INDUSTRY GROUP 1

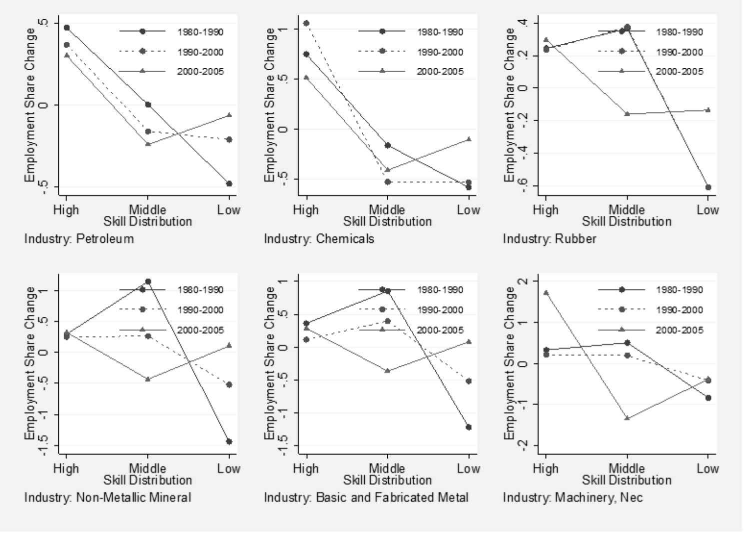

FIGURE 2

ANNUAL CHANGE IN EMPLOYMENT SHARE

BY TYPE OF SKILLED WORKERS FOR INDUSTRY GROUP 2

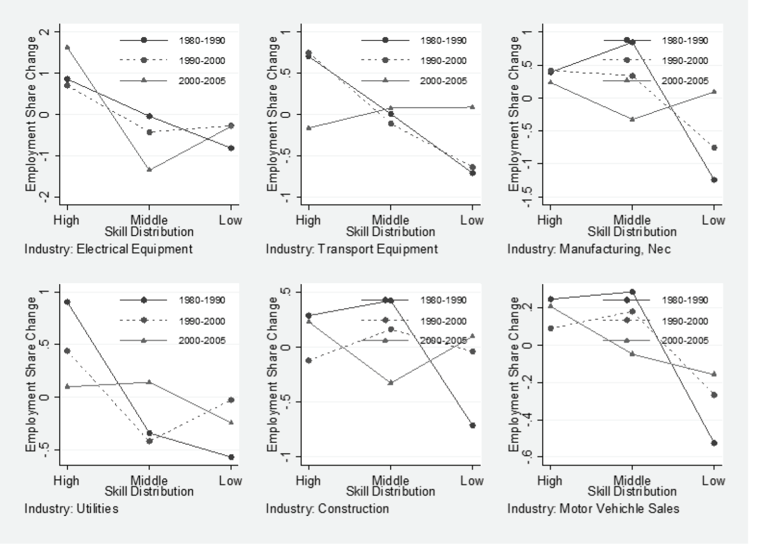

FIGURE 3
ANNUAL CHANGE IN EMPLOYMENT SHARE
BY TYPE OF SKILLED WORKERS FOR INDUSTRY GROUP 3

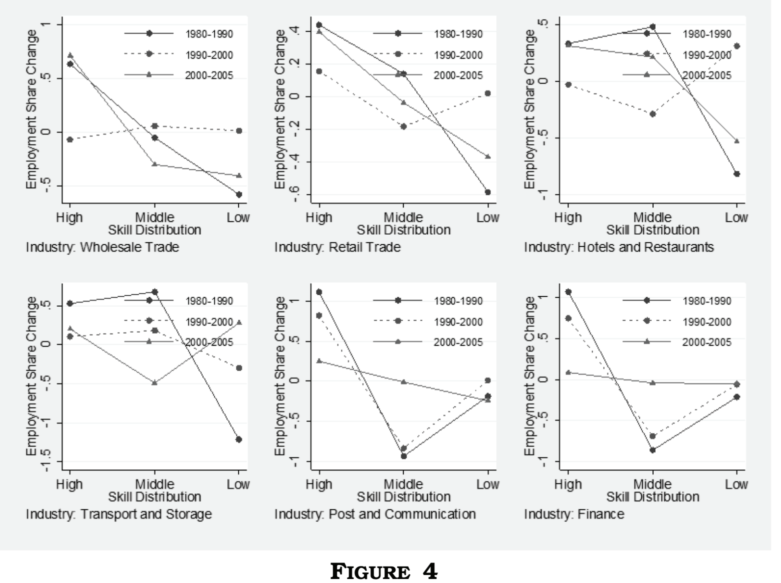

FIGURE 4
ANNUAL CHANGE IN EMPLOYMENT SHARE
BY TYPE OF SKILLED WORKERS FOR INDUSTRY GROUP 4

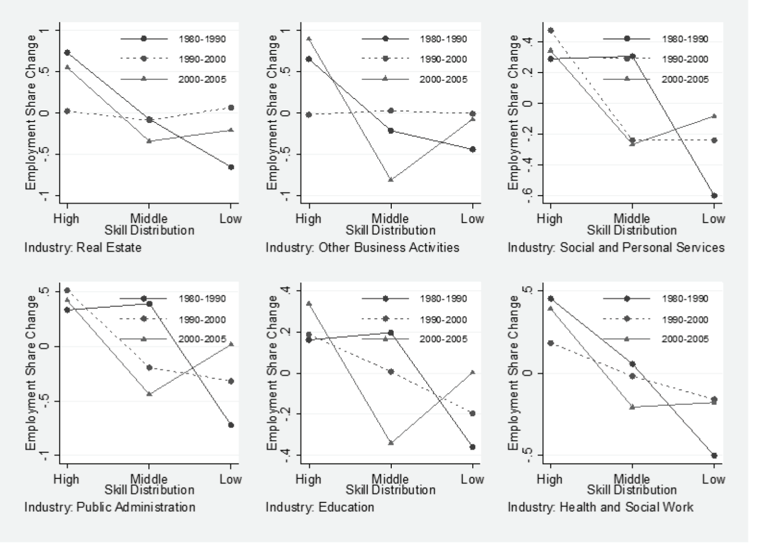

FIGURE 5
ANNUAL CHANGE IN EMPLOYMENT SHARE
BY TYPE OF SKILLED WORKERS FOR INDUSTRY GROUP 5

changes in share by decade and in the long term.

Since 1970, the employment growth by type of skilled workers is mainly attributed to within-industry changes. Though the employment growth of high-skilled workers in the 1990s has decreased, compared to other decades, the share level of high-skilled workers has been increasing over decades in both employment and wage bill. On the other hand, the middle panel shows that the employment growth of middle-skilled workers has decreased by the period 1980-1990, becoming negative thereafter. We can also see this pattern in the long-term changes. The employment growth of low-skilled workers has been negative over all decades, but the decrease in share of employment has moderated. This result seems to imply that as in the routinization hypothesis, the polarized employment structure began to appear in the 1990s, leading to a decrease in demand for middle-skilled workers but an increase in demand for low-skilled workers, along with a modest increase for high-skilled workers.

TABLE 3
STANDARD SHIFT-SHARE DECOMPOSITION OF CHANGES IN SKILL DEMAND

Variables	Employment			Wage Bill		
	Total	Between	Within	Total	Between	Within
	Nonroutine Cognitive Tasks (High-Skilled Workers)					
Changes by Decade						
1970-1980	0.943	0.080	0.863	0.973	0.121	0.853
		(0.085)	(0.915)		(0.124)	(0.876)
1980-1990	0.674	0.136	0.538	0.937	0.181	0.757
		(0.202)	(0.798)		(0.193)	(0.807)
1990-2000	0.485	0.076	0.409	0.687	0.101	0.587
		(0.157	(0.843)		(0.146)	(0.854)
2000-2005	0.819	0.323	0.496	1.284	0.420	0.863
		(0.394)	(0.606)		(0.328)	(0.673)
Long-Term Changes						
1970-1990	0.820	0.108	0.712	0.980	0.150	0.830
		(0.131)	(0.869)		(0.153)	(0.847)
1990-2005	0.605	0.154	0.451	0.830	0.203	0.626
		(0.255)	(0.745)		(0.245)	(0.755)
	Routine Tasks (Middle-Skilled Workers)					
Changes by Decade						
1970-1980	0.888	0.017	0.871	0.612	-0.025	0.637
		(0.019)	(0.981)		(-0.041)	(1.041)
1980-1990	0.335	0.037	0.298	0.013	-0.010	0.024
		(0.110)	(0.890)		(-0.755)	(1.755)
1990-2000	-0.164	-0.058	-0.106	-0.359	-0.081	-0.278
		(0.354)	(0.646)		(0.226)	(0.774)
2000-2005	-0.075	0.227	-0.302	-0.537	0.133	-0.670
		(-3.049)	(4.049)		(-0.247)	(1.247)
Long-Term Changes						
1970-1990	0.555	0.026	0.529	0.234	-0.017	0.251
		(0.047)	(0.953)		(-0.073)	(1.073)
1990-2005	-0.154	0.039	-0.193	-0.362	-0.006	-0.356
		(-0.256)	(1.256)		(0.018)	(0.982)
	Nonroutine Manual Tasks (Low-Skilled Workers)					
Changes by Decade						
1970-1980	-1.800	-0.067	-1.734	-1.555	-0.065	-1.490
		(0.037)	(0.963)		(0.042)	(0.958)
1980-1990	-0.882	-0.046	-0.835	-0.824	-0.044	-0.780
		(0.052)	(0.948)		(0.053)	(0.947)
1990-2000	-0.313	-0.010	-0.303	-0.320	-0.011	-0.309
		(0.031)	(0.969)		(0.034)	(0.966)
2000-2005	-0.205	-0.010	-0.195	-0.207	-0.014	-0.193
		(0.050)	(0.950)		(0.067)	(0.933)
Long-Term Changes						
1970-1990	-1.296	-0.055	-1.241	-1.136	-0.054	-1.081
		(0.043)	(0.957)		(0.048)	(0.952)
1990-2005	-0.266	-0.008	-0.257	-0.282	-0.011	-0.271
		(0.031)	(0.969)		(0.040)	(0.960)

III. Empirical Results

A. Heterogeneous Effects of Computerization on the Shares of Skilled Workers: Pre- and Post-1995 Periods

Using the aforementioned shift-share analysis, we observe that most changes in the employment and wage bill share of skilled workers within a specific industry, which is consistent with the prediction suggested by Autor *et al.* (2003, 2006), apply to all industries. The analysis in this section aims to facilitate understanding of how the adoption of computerization in each industry is related to the shares of the skilled workers across industries.

In practice, the rapid adoption of computer-related technology driven by a decline in the real price of information and communication technology can have a heterogeneous effect on the demand for skilled worker types. For example, the diffusion of computer-related technology in business involves the routinization of white-collar jobs, such as simple and repetitive tasks in the office, rather than more complex and idiosyncratic tasks. Moreover, the computerization related to microprocessor technologies has been easily applied to the automation of the production process in the manufacturing industries (Autor *et al.*, 1998; Autor *et al.*, 2003; Bresnahan, 1999). Furthermore, the rapid computerization applied to the business system or manufacturing, which replaces human labor inputs in clerical or assembly-line jobs, requires the cognitive skills of more educated workers.

Together with the direct substitution of computers for middle-skilled jobs, therefore, the organizational complementarities between computerization and high-skilled workers would facilitate an increase in the relative demand for high-skilled workers, in concurrence with a decrease in demand for middle-skilled workers. To present the heterogeneous effects of computerization on the demand for the three types of skilled workers, we use the empirical model with a period dummy of 1995, the widely accepted year characterized by a sharp increase in computerized assets in the United States suggested by Jorgenson (2001) and Stiroh (2002):[3]

$$\Omega^i_{kt} = \beta_0 + \beta_1 \ln ICT_{kt} + \beta_2 \ln Y_{kt} + \beta_3 \ln K_{kt} + \beta_4 \Phi_t \quad (3)$$

[3] The trigger for an accelerating decline in price of information technology in 1995 appears to have been a rapid decrease in the price of semiconductors in 1994.

$$+\beta_5\Phi_t\times\ln ICT_{kt}+\beta_6\Phi_t\times\ln Y_{kt}+\mu_k+\varepsilon_{kt},$$

where Ω^i_{kt} represents the share of employment or wage bill for task i, *i.e.*, nonroutine cognitive, routine (routine cognitive and routine manual), and nonroutine manual tasks, in industry k at time t. ICT_{kt} refers to the investment in computer-related technology, measured by real gross fixed capital formation, Y_{kt}, a real gross value added. K_{kt} indicates a capital stock measured by real fixed capital stock, and Φ_t, a period dummy of post-1995. Thus, β_1 denotes the effect of computerization on skill demand for the pre-1995 period, and $\beta_1+\beta_5$ refers to the effect of computerization on skill demand for the post-1995 period. Thus, the coefficient β_5 denotes the pure effects of post-1995 computerization on the employment share.

Table 4 shows the empirical results by type of skilled workers in terms of employment and wage bill, consistent with the routinization hypothesis. At both the panels in Table 4, computerization increased the employment and wage bill share of high- and middle-skilled workers before 1995. These results indicate that computer-based capital is complementary to both high- and middle-skilled workers. The share of low-skilled workers was, however, decreased by the computerization.

With the interaction term of post-1995 and ICT (β_5) estimated positively for high- and low-skilled workers, we can see that the post-1995 computerization, which can be characterized by a decline in the price of computers, has accelerated the increase in employment and wage bill share of the high-skilled workers, but mitigated the decrease in the share of the low-skilled workers. For the middle-skilled workers, on the other hand, post-1995 computerization moderated the positive computerization effects before 1995 with the negative $\hat{\beta}_5$)'s. Evidently, the data show that since 1995, a polarized pattern of employment emerged in the U.S. labor market, owing to the prevalent use of computers resulting from a decline in the price of computers. In this context, while the employment and wage bill share of the low-skilled decreased throughout the whole sample period, the computer diffusion paradoxically seems to have played a role in buffering such a rapid decrease as it caused the middle-skilled jobs at the lower margin to be incorporated into the low-skilled tier.

B. Heterogeneous Effects of Computerization on the Shares of Skilled Workers by Industry Group: Pre- and Post-1995 Periods

In this section, we focus on examining the heterogeneous effects of computerization on skill demand by re-classifying industries in hand into three groups in terms of the extent of investment in computer-related capital over the period 1970-2005: high-, middle-, and low-computerized industry. Autor *et al.* (2003) argue that industries, which have a set of routine tasks substitutable with computer-related assets, would have an incentive to invest more in newly-advanced computer capital. As a result, depending on the extent of adopted computer-related assets at the industry level, the effects of computerization on the demand of skill would be clearly heterogeneous.

To this end, we define the high-, middle-, and low-computerized industry groups as industries above the 75^{th} percentile, between the 25^{th} and 75^{th} percentiles, and below the 25^{th} percentile, respectively, in terms of the extent of investment in computer-related capital. More specifically, the high-computerized industry group includes "Transport and Storage," "Post and Communication," "Financial Intermediation," and so on; the middle-computerized group, "Mining and Quarrying," "Food, Beverages and Tobacco," "Pulp, Paper, Printing and Publishing," and so on; and the low-computerized group, "Construction," "Manufacturing, Nec, and Recycling," "Hotels and Restaurants," and so on.

Tables 5, 6, and 7 show the comparisons of the computerization effects on the demand for the three types of skilled workers in the U.S. labor market by industry group. Notably, the empirical results in all these tables are arranged in the same manner as those in Table 4. Table 5 shows that the effects of computerization on the demand for skill within the high-computerized industry group are also similar to those in Table 4, consistent with the routinization hypothesis. Table 6 shows the empirical results in the middle-computerized group, which are also consistent with the routinization hypothesis. The positive effects of computerization on demand for the low-skilled workers, however, are greater than that for the high-skilled workers, compared to those in the high-computerized group in Table 5. For the middle-computerized industries, this finding suggests that the post-1995 computerization causes the middle-skilled workers at the margin to be relegated to the low-skilled more than to the high-skilled. In Table 7, the computerization after 1995 negatively affects the employment share of middle-skilled workers in the low-computerized group, leading the negative effects to

TABLE 4

EFFECTS OF COMPUTERIZATION ON THE SHARES OF SKILLED WORKERS

Variables	Dependent Variable: Shares by Each Type of Skilled Workers					
	High-Skilled		Middle-Skilled		Low-Skilled	
	(1)	(2)	(1)	(2)	(1)	(2)
			Employment			
Log Computerization	1.034*** (0.061)	0.928*** (0.012)	3.510*** (0.115)	3.715*** (0.027)	-4.297*** (0.121)	-4.720*** (0.014)
Log Value Added	2.432*** (0.208)	2.813*** (0.020)	-1.541*** (0.288)	-1.410*** (0.038)	-1.676*** (0.306)	-1.407*** (0.014)
Log Capital Stock	6.077*** (0.290)	5.911*** (0.045)	-6.784*** (0.518)	-7.449*** (0.079)	0.951 (0.599)	1.614*** (0.070)
Post-1995 Period	7.223*** (1.335)	11.783*** (0.193)	3.841* (2.291)	8.188*** (0.206)	-15.412*** (2.709)	-20.213*** (0.353)
Post-1995 Period × Log ICT	0.305** (0.130)	0.474*** (0.015)	-2.131*** (0.198)	-2.228*** (0.046)	1.848*** (0.219)	1.754*** (0.026)
Post -1995 Period × Log VA	-0.855*** (0.161)	-1.319*** (0.026)	1.038*** (0.251)	0.707*** (0.036)	0.125 (0.274)	0.643*** (0.017)
Intercept	-99.276*** (3.633)	-101.132*** (0.569)	144.250*** (6.011)	150.473*** (1.200)	59.987*** (6.487)	50.027*** (1.165)
Industry Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,116	1,116	1,116	1,116	1,116	1,116
			Wage Bill			
Log Computerization	1.677*** (0.087)	1.643*** (0.016)	3.217*** (0.119)	3.253*** (0.022)	-4.404*** (0.119)	-4.934*** (0.017)
Log Value Added	4.351*** (0.284)	4.276*** (0.027)	-2.821*** (0.317)	-2.872*** (0.036)	-1.811*** (0.311)	-1.375*** (0.026)
Log Capital Stock	5.461*** (0.426)	5.972*** (0.084)	-8.631*** (0.602)	-9.233*** (0.056)	2.581*** (0.588)	3.261*** (0.054)
Post-1995 Period	16.139*** (1.837)	21.470*** (0.480)	-1.170 (2.517)	3.974*** (0.238)	-19.882*** (2.703)	-25.647*** (0.470)
Post-1995 Period × Log ICT	0.977*** (0.187)	0.648*** (0.027)	-2.277*** (0.222)	-2.160*** (0.045)	1.561*** (0.219)	1.552*** (0.029)
Post -1995 Period × Log VA	-2.006*** (0.230)	-2.176*** (0.048)	1.480*** (0.289)	0.986*** (0.030)	0.653** (0.275)	1.185*** (0.042)
Intercept	-109.764*** (5.096)	-115.568*** (1.212)	184.229*** (6.711)	192.381*** (0.893)	34.606*** (6.369)	23.023*** (0.982)
Industry Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,116	1,116	1,116	1,116	1,116	1,116

Notes: The figures in parentheses are standard errors. * is significant at 10% level, ** significant at 5% level, and *** significant at 1% level. The two models for each type of skilled workers are estimated by considering heteroskedastic structure and both heteroskedastic and correlated error structure, respectively.

TABLE 5

EFFECTS OF COMPUTERIZATION ON THE SHARES OF SKILLED WORKERS: HIGH-COMPUTERIZED INDUSTRY GROUP

Variables	Dependent Variable: Shares by Each Type of Skilled Workers					
	High-Skilled		Middle-Skilled		Low-Skilled	
	(1)	(2)	(1)	(2)	(1)	(2)
			Employment			
Log Computerization	4.247***	3.828***	1.495***	1.428***	-5.575***	-5.017***
	(0.231)	(0.171)	(0.291)	(0.131)	(0.203)	(0.108)
Log Value Added	9.118***	9.522***	-8.637***	-7.449***	-1.121***	-1.436***
	(0.391)	(0.213)	(0.425)	(0.149)	(0.302)	(0.187)
Log Capital Stock	-8.273***	-8.665***	6.039***	5.250***	2.311***	2.852***
	(0.359)	(0.120)	(0.433)	(0.143)	(0.370)	(0.223)
Post-1995 Period	-31.554***	-29.041***	61.641***	50.353***	-35.660***	-26.653***
	(9.066)	(5.860)	(11.265)	(4.902)	(7.525)	(4.670)
Post-1995 Period × Log ICT	2.182***	2.957***	-7.113***	-5.164***	2.519***	2.496***
	(0.585)	(0.375)	(0.799)	(0.371)	(0.524)	(0.307)
Post -1995 Period × Log VA	0.522	-0.245	0.803	0.018	1.042**	0.337
	(0.689)	(0.414)	(0.807)	(0.246)	(0.479)	(0.236)
Intercept	-17.238***	-14.340***	79.522***	76.535***	43.172***	34.905***
	(3.227)	(2.053)	(4.631)	(1.491)	(2.951)	(1.796)
Observations	252	252	252	252	252	252
			Wage Bill			
Log Computerization	5.310***	4.715***	-0.577*	-0.175	-4.654***	-4.417***
	(0.284)	(0.247)	(0.327)	(0.207)	(0.164)	(0.101)
Log Value Added	14.370***	14.509***	-12.609***	-11.488***	-1.917***	-2.171***
	(0.495)	(0.264)	(0.499)	(0.221)	(0.247)	(0.191)
Log Capital Stock	-12.599***	-13.000***	9.607***	9.306***	2.627***	3.151***
	(0.399)	(0.186)	(0.453)	(0.202)	(0.300)	(0.200)
Post-1995 Period	-35.368***	-54.116***	69.241***	68.895***	-24.582***	-22.588***
	(12.963)	(7.177)	(13.401)	(6.732)	(5.409)	(3.785)
Post-1995 Period × Log ICT	3.767***	4.994***	-7.677***	-6.471***	1.906***	2.193***
	(0.745)	(0.505)	(0.881)	(0.513)	(0.410)	(0.268)
Post -1995 Period × Log VA	-0.447	0.053	0.776	-0.268	0.623*	0.220
	(0.989)	(0.603)	(0.994)	(0.362)	(0.371)	(0.189)
Intercept	-26.947***	-19.039***	94.433***	81.440***	38.309***	32.704***
	(4.924)	(2.437)	(5.426)	(1.890)	(2.011)	(1.415)
Observations	252	252	252	252	252	252

Notes: The figures in parentheses are standard errors. * is significant at 10% level, ** significant at 5% level, and *** significant at 1% level. The two models for each type of skilled workers are estimated by considering heteroskedastic structure and both heteroskedastic and correlated error structure, respectively.

TABLE 6

EFFECTS OF COMPUTERIZATION ON THE SHARES OF SKILLED WORKERS: MIDDLE-COMPUTERIZED INDUSTRY GROUP

Variables	Dependent Variable: Shares by Each Type of Skilled Workers					
	High-Skilled		Middle-Skilled		Low-Skilled	
	(1)	(2)	(1)	(2)	(1)	(2)
			Employment			
Log Computerization	2.823***	2.727***	1.897***	1.968***	-4.796***	-4.795***
	(0.227)	(0.078)	(0.162)	(0.068)	(0.157)	(0.084)
Log Value Added	3.771***	1.846***	-2.125***	-2.949***	0.713**	1.146***
	(0.508)	(0.044)	(0.307)	(0.066)	(0.346)	(0.055)
Log Capital Stock	1.265***	2.195***	-0.264	-0.112	-2.423***	-2.035***
	(0.256)	(0.073)	(0.194)	(0.076)	(0.210)	(0.072)
Post-1995 Period	18.088**	-2.373**	27.475***	26.419***	-42.909***	-24.407***
	(8.352)	(0.950)	(5.176)	(1.389)	(6.347)	(0.999)
Post-1995 Period × Log ICT	-1.421**	1.035***	-2.681***	-3.583***	3.230***	3.069***
	(0.636)	(0.164)	(0.450)	(0.171)	(0.518)	(0.227)
Post -1995 Period × Log VA	-0.523	-0.732***	-0.427	0.335***	1.428**	0.045
	(0.702)	(0.112)	(0.497)	(0.114)	(0.571)	(0.151)
Intercept	-59.082***	-45.168***	76.541***	83.766***	70.552***	61.039***
	(4.481)	(0.822)	(2.805)	(0.761)	(3.277)	(0.676)
Observations	576	576	576	576	576	576
			Wage Bill			
Log Computerization	3.618***	3.488***	1.452***	0.937***	-4.415***	-4.578***
	(0.288)	(0.100)	(0.241)	(0.063)	(0.136)	(0.069)
Log Value Added	3.831***	3.139***	-1.155**	-3.451***	-0.164	0.381***
	(0.668)	(0.072)	(0.553)	(0.088)	(0.330)	(0.072)
Log Capital Stock	1.934***	2.632***	-1.318***	-0.949***	-2.075***	-1.639***
	(0.311)	(0.102)	(0.289)	(0.082)	(0.171)	(0.065)
Post-1995 Period	12.052	-1.327	40.035***	29.902***	-50.258***	-31.601***
	(11.488)	(1.526)	(9.450)	(2.166)	(6.081)	(1.489)
Post-1995 Period × Log ICT	-2.019**	1.177***	-2.305***	-3.634***	2.974***	3.217***
	(0.826)	(0.233)	(0.707)	(0.178)	(0.454)	(0.206)
Post -1995 Period × Log VA	0.541	-0.875***	-1.998**	0.069	2.166***	0.520***
	(0.951)	(0.171)	(0.802)	(0.169)	(0.514)	(0.152)
Intercept	-65.879***	-62.912***	77.680***	102.204***	70.952***	60.290***
	(6.163)	(1.248)	(4.915)	(1.108)	(3.113)	(0.836)
Observations	576	576	576	576	576	576

Notes: The figures in parentheses are standard errors. * is significant at 10% level, ** significant at 5% level, and *** significant at 1% level. The two models for each type of skilled workers are estimated by considering heteroskedastic structure and both heteroskedastic and correlated error structure, respectively.

TABLE 7
EFFECTS OF COMPUTERIZATION ON THE SHARES OF SKILLED WORKERS: LOW-COMPUTERIZED INDUSTRY GROUP

Variables	Dependent Variable: Shares by Each Type of Skilled Workers					
	High-Skilled		Middle-Skilled		Low-Skilled	
	(1)	(2)	(1)	(2)	(1)	(2)
			Employment			
Log Computerization	1.608***	1.464***	3.573***	3.619***	-5.202***	-5.100***
	(0.083)	(0.044)	(0.167)	(0.095)	(0.190)	(0.133)
Log Value Added	-0.855***	-0.732***	4.238***	3.341***	-3.247***	-2.748***
	(0.198)	(0.104)	(0.486)	(0.215)	(0.584)	(0.280)
Log Capital Stock	1.499***	1.519***	-1.161***	-1.411***	-0.489	-0.093
	(0.189)	(0.093)	(0.387)	(0.143)	(0.428)	(0.138)
Post-1995 Period	28.019***	22.800***	73.984***	48.802***	-96.474***	-72.884***
	(3.531)	(1.732)	(8.503)	(4.679)	(9.169)	(5.972)
Post-1995 Period × Log ICT	-0.010	-0.023	-2.735***	-2.711***	2.874***	2.579***
	(0.303)	(0.118)	(0.663)	(0.299)	(0.701)	(0.302)
Post -1995 Period × Log VA	-2.523***	-2.027***	-5.010***	-2.870***	6.998***	5.083***
	(0.395)	(0.202)	(0.926)	(0.486)	(0.967)	(0.579)
Intercept	-5.705***	-6.748***	7.929*	20.964***	98.474***	87.254***
	(1.901)	(0.818)	(4.283)	(2.071)	(4.706)	(2.783)
Industry Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	288	288	288	288	288	288
			Wage Bill			
Log Computerization	2.786***	2.568***	2.623***	2.597***	-5.329***	-5.223***
	(0.139)	(0.070)	(0.141)	(0.094)	(0.198)	(0.122)
Log Value Added	-2.289***	-2.367***	4.083***	3.613***	-1.308**	-1.458***
	(0.293)	(0.167)	(0.450)	(0.272)	(0.580)	(0.287)
Log Capital Stock	3.091***	2.819***	-1.456***	-1.903***	-1.991***	-1.122***
	(0.303)	(0.166)	(0.382)	(0.252)	(0.425)	(0.212)
Post-1995 Period	64.550***	49.087***	38.223***	14.632***	-92.350***	-77.974***
	(5.690)	(4.029)	(8.262)	(4.155)	(9.378)	(6.235)
Post-1995 Period × Log ICT	-0.202	0.035	-2.672***	-2.536***	2.330***	1.814***
	(0.497)	(0.233)	(0.620)	(0.312)	(0.707)	(0.325)
Post -1995 Period × Log VA	-5.569***	-4.309***	-1.796**	0.128	6.820***	5.874***
	(0.664)	(0.445)	(0.892)	(0.432)	(0.960)	(0.597)
Intercept	-8.105***	-3.387*	16.627***	27.376***	90.510***	80.926***
	(3.118)	(1.875)	(4.113)	(1.841)	(4.872)	(3.020)
Industry Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	288	288	288	288	288	288

Notes: The figures in parentheses are standard errors. * is significant at 10% level, ** significant at 5% level, and *** significant at 1% level. The two models for each type of skilled workers are estimated by considering heteroskedastic structure and both heteroskedastic and correlated error structure, respectively.

an increase only in the low-skilled.

To summarize, we observe that the routine hypothesis problem is more serious in the high-computerized industry group than in the middle- and low-computerized groups, with evidence of the possible replacement of middle-skilled jobs at the margin with low-skilled jobs.

IV. Concluding Remarks

Prior to the emergence of the polarized structure of employment in the U.S. labor market since 1990, the SBTC hypothesis is primarily adopted to examine changes in employment structure. However, to explain the polarization in the employment structure attributed to a rapid increase in employment of high-skilled workers, a decrease in middle-skilled workers, and a modest increase in low-skilled workers, the SBTC hypothesis, which suggests uniform shifts in demand from the lower skill distribution toward the higher skill distribution, seems to have given us limited implications, along with the necessity for more sophisticated models.

In this context, Autor *et al.* (2003) provide a simple economic model, describing how new advances in computer-related technology affect changes in task and skill demand of workers. The model shows that the increased adoptions of computer-related technology attributed to a rapid decline in the price of computer-related capital substitute for human labor inputs in routine tasks and simultaneously increase the demand for high-skilled workers to perform nonroutine cognitive tasks, complementary to computer-related equipment.

In this paper, we attempted to determine how computerization heterogeneously affects the demand for each of the three types of skilled workers, a rationale for the polarization of employment in the recent U.S. labor market. Consistent with the routinization hypothesis by Autor *et al.* (2003), our empirical results show that an expansion in the adoption of computer-related assets increases the skill demand for high- and low-skilled workers, but decreases that for middle-skilled workers. Furthermore, given the expansion of computerization, the job polarization in high- computerized industries is distinct, relative to middle- and low-computerized industries. Therefore, our empirical analyses provide supporting evidence that heavy investments in computerization are meaningful to explain recent changes in employment toward a polarized structure in the U.S. labor market.

Nonetheless, this paper has some limitations in that we find no other variables than schooling to measure worker skill, and that we analyze the U.S. labor market only. We hereby hope that future research will be conducted to mitigate these problems.

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