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TECHNOLOGY AND THE DEMAND FOR SKILLS: AN INDUSTRY-LEVEL ANALYSIS

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TECHNOLOGY AND THE DEMAND FOR SKILLS: AN INDUSTRY-LEVEL ANALYSIS

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ABSTRACT

This paper examines the effect of technological change on the relative demand for skilled workers across Canadian industries. Using data from a number of Canadian labour market surveys, the paper explores two questions: (1) has skill intensity risen across industries over the 1981–94 period; and (2) is biased technological change the main cause of the shift in demand toward skilled workers? We proceed in two steps. First, we use broader occupational distinctions to develop two alternative industry-based skill measures — one based on the skill classification identified in the National Occupational Classification (NOC), and the other based on the skill classification scheme proposed by Wolff and Baumol (1989). Second, we combine data on skills with four industry-level measures of technology: the stock of research and development (R&D), the stock of patents used by the industry, total factor productivity, and the age of the capital stock.

A simple supply-demand framework is used to interpret changes in the relative quantities and wages of workers over the 1981–94 period. The results suggest that the relative supply of skilled workers increased and relative wages remained stable or fell slightly. Thus we infer that relative demand rose. We find that the rise in skill intensity is pervasive across Canadian industries. The shift in demand for more-skilled workers since the beginning of the 1980s is entirely driven by "within-industry" skill utilization rather than "between-industry" employment shifts. This is true both in manufacturing and in services. As argued by Berman, Bound and Griliches (1994), this evidence seems consistent with the view that biased technological change played a dominant role in skill upgrading. The technology indicators — R&D capital, stock of patents used by the industry, age of the capital stock — are generally found to be strongly correlated with skill intensity. From this we infer that biased technological change has been a key factor to within-industry skill upgrading across Canadian industries. These results imply that skill upgrading has occurred both in industries that invested heavily in new capital during the 1980s and in those that are R&D capital-intensive.

1. INTRODUCTION

During the past decade there has been a considerable amount of research on the impact of technological change on skill differentials in U.S. labour markets. One line of research has focused on the documentation and explanation of the rise in skill intensity during the 1980s (e.g., Katz and Murphy, 1992; Bound and Johnson, 1992; Berman, Bound and Griliches, 1994). While the increase in skill intensity has been well documented, there is no consensus as to its explanation. Skill-biased technological change has been offered as a major explanation for this relative employment shift (Berman, Bound and Griliches, 1994; Berman, Bound and Machin, 1997; Autor, Katz and Krueger, 1997; Berndt, Morrison, and Rosenblum, 1992). These studies support this conclusion by finding strong correlations between skill upgrading within industries and employee computer usage, investment in computers and R&D expenditures.[1]

Alternative explanations have pointed to international factors, particularly trade, as the source of these employment shifts (e.g., Leamer, 1995; Wood, 1994; Borjas and Ramey, 1995). However, the precise role of international trade in these shifts remains unclear. Sachs and Shatz (1994) find that trade played only a partial role in explaining what happened in labour markets. Yet, others find evidence that is inconsistent with the trade explanation (Katz and Murphy, 1992; Lawrence and Slaughter, 1993).

A second line of research has attempted to explain the widening skill (education) wage differentials since the early 1980s. Most studies argue in support of biased technological change and trade as major explanations (e.g., Bound and Johnson, 1992; Berman, Bound and Griliches, 1994; Krueger, 1993; Wood, 1994; Borjas, 1995). Krueger (1993) corroborates the importance of biased technological progress by documenting that from one to two thirds of the 1984-89 increase in the premium on education was related to the use of computers.[2] Bartel and Lichtenberg (1991) find that industries that use young technologies pay a premium wage.[3]

Other studies argue that the increasing internationalization of the U.S. labour market, through both immigration and trade, has had an important impact on the wage structure (Borjas, 1995). Borjas, Freeman and Katz (1992) find that trade flows explain, at the most, 15 percent of the increase in earnings differentials in the 1980s between college-educated workers and their high school-educated counterparts. Lawrence and Slaughter (1993) find that trade played basically no role in U.S. wage changes in the 1980s.

Katz and Murphy (1992) show that a possible driving force behind increasing wage differentials in the 1980s has been a slowdown in the rate of growth of the relative supply of college workers accompanied by continued growth in the relative demand for more-educated workers.

Finally, institutional explanations for the rise in wage inequality focus on changes in wage-setting institutions — decline in unions, real minimum wage, and other pay-setting norms that have historically served to compress the wage structure (e.g., Freeman, 1996; DiNardo, Fortin and Lemieux, 1996).

There is also a growing Canadian literature on the issue of rising wage inequality in the 1980s (e.g., Blackburn, Bloom and Freeman, 1990; Freeman and Needels, 1993; Kuhn, 1995; Burbidge, Magee and Robb, 1996). Freeman and Needels (1993) find that the college-high school wage differential increased only slightly in Canada during the 1980s. In a recent paper, Murphy, Riddell and Romer (1997) focus on the recent growth of educational wage differentials in Canada and the United States. Using the Katz and Murphy (1992) methodolgy, their findings show that the university wage premium varies substantially both over time and between countries. In the United States, it grew during the 1960s and fell during the 1970s. Over the 1980s, the premium grew in the United States but declined somewhat in

Canada. The authors argue that relative supply changes seem to explain the difference in the behaviour of wages in the two countries, a finding consistent with those of Freeman and Needels (1993).

Based on the data from the 1994 General Social Survey, Morissette and Drolet (1997) find that computer use is associated with a wage premium of about 14 percent. The authors suggest that the computer use premium probably reflects unobserved characteristics of workers and firms. Utilizing establishment level data for the manufacturing sector, Baldwin, Gray and Johnson (1997) find that establishments using advanced technologies pay higher wages than other establishments.[4] A study by Baldwin and Rafiquzzaman (1998) finds that both trade and technology have contributed to the widening wage gap between production and nonproduction workers in the manufacturing sector during the 1980s.

On the issue of skill upgrading in Canada, very little work has been done and what is available suggests contradictory findings. Lee (1996) fails to find a positive correlation between technical change and the intensive use of nonproduction labour in manufacturing during the 1980s. In contrast, Baldwin and Rafiquzzaman (1998) find strong evidence that advanced technologies are complementary with more-skilled workers in manufacturing. Of course, these studies use different data sets and methodologies in arriving at their conclusions.[5]

In this paper, we attempt to evaluate whether biased technological change has led to an increase in demand for skilled workers across Canadian industries during the 1980s and early 1990s. We proceed in two steps: (1) we document that indeed skill intensity (defined as the wage bill share or employment share of skilled workers) rose across Canadian industries over this period; and (2) we examine the relationship between skill upgrading and observable indicators of technological change.

We first present evidence on trends in hours worked, wage bill shares, and wages of workers by skills in Canadian industries from 1981 to 1994. The data reveal that the relative return to skills remained stable while the labour force was becoming more skilled (educated) over the period. In terms of a conventional market-clearing model of the labour market, the observation of a stable relative price of skill in the face of an increase in its relative supply means that the relative demand for skills must have increased over the period.

We find that growth in demand for skills during the 1980s and early 1990s in both manufacturing and service sectors is entirely explained by “within-industry” skill upgrading rather than “between-industry” employment shifts. We explore the role of technological change in the growth of relative demand for skilled workers by linking industry skill data with several alternative measures of technology, including age of the capital stock, R&D capital stock, stock of patents used, and total factor productivity (TFP). Overall, we find a positive and significant relationship between technological change and skill upgrading for many of the indicators used. From this evidence, we infer that biased technological change has been responsible for the shift in demand towards skilled labour in Canadian industries during the 1980s and early 1990s.

We would like to mention two distinctive features of our study. First, the data are drawn from a number of Statistics Canada labour market surveys: the Survey of Work History for 1981, the Labour Market Activity Survey for the years 1986 to 1990, and the Survey of Labour and Income Dynamics for 1993 and 1994. Unlike the previous studies that have focused on skill upgrading within the manufacturing sector, we use information on 29 industries in both the manufacturing and the service sectors. Second, identifying the skill level of workers is always a problem in empirical work. The proper measurement of a worker’s skill level probably requires a broad range of data including education, on-the-job training, and work experience. However, faced with limited data, most previous studies have used occupational distinctions to define nonproduction and production workers. The former group is usually called “skilled” and the latter group “unskilled.” In our analysis, we use broader occupational distinctions to develop two alternative measures of skills — one based on the skill classification identified in the National Occupational Classification (NOC), and the other based on the skill classification scheme proposed by Wolff and Baumol (1989). These issues are discussed in detail in the next section.

2. IDENTIFYING THE SKILL LEVEL OF WORKERS

The data that we use is drawn from a number of Statistics Canada's Labour Market Surveys. These include the Survey of Work History (SWH) for 1981, the Labour Market Activity Survey (LMAS) for the years 1986 to 1990, and the Survey of Labour and Income Dynamics (SLID) for 1993 and 1994. The SWH provides information on earnings and hours worked on up to four jobs held by an individual in 1981. The LMAS and the SLID provide information on earnings and hours worked for up to five jobs held by an individual in a survey year. Jobs in all these surveys are assigned to an industry (based on the Standard Industrial Classification, 1980) and an occupation (based on the Standard Occupational Classification, 1980). We aggregate earnings and hours worked on all jobs into two sets of matrices: total earnings by industry and occupation, and total hours worked by industry and occupation. We exclude jobs in primary industries and in public sector industries because good measures of technological change are not available for these industries. In the final analysis, we end up with 29 industries and 48 occupations.

Given the complexity and multi-dimensional nature of skills involved in performing certain occupations, it is unlikely that there exists a single perfect skill classification of occupations. Accordingly, we develop two alternative occupation-based measures of worker skills in this paper: (1) based on the National Occupational Classification (NOC); and (2) based on the classification scheme proposed by Wolff and Baumol (1989).

The NOC Skill Classification Criteria

The NOC presents a new structure for analyzing and understanding the labour market and reflects occupational changes that have taken place over the past two decades. The NOC identifies four skill level categories — professional workers (skill level A), technical skilled workers (skill level B) intermediate workers (skill level C) and unskilled workers (skill level D). All occupations in the NOC are assigned a skill level category based upon the amount and type of education and training required to enter and perform the duties of the occupation.[6] The NOC does not assign a skill level category to management occupations because factors other than education and training are considered significant determinants for employment.

The data on employment and wages obtained from the various labour market surveys are coded according to the 1980 Standard Occupational Classification (SOC). The 1980 SOC occupations are assigned to one of the NOC skill level categories based on the concordance between the SOC (1980) and the NOC. Details on the NOC skill classification of occupations are described in Table A1 of the Appendix.

Given the ambiguity in assigning some occupations to either intermediate or unskilled occupations, we combine these two skill categories into one category and call this group "less-skilled or unskilled." Similarly, we define professional, technical skilled workers and managerial workers as a "more-skilled" or "skilled" group. In our subsequent discussions, we use terms such as the NOC skilled workers and the NOC unskilled workers.

Wolff and Baumol (1989) Skill Classification Scheme

Another measure of skills is based on the occupational classification scheme proposed by Wolff and Baumol (1989). Under the Wolff and Baumol classification scheme, an occupation can be classified into one of four skill categories: “knowledge” workers, “data” workers, “goods” workers, and “services” workers.[7]

Knowledge workers are mainly involved in generating knowledge or expert opinions while data workers — such as most clerical workers — use, manipulate or transmit knowledge. Knowledge workers require at least a college degree and, in most cases, a university degree, while data workers require, in general, less than a college or a technical degree. The goods workers category is defined to include workers that transform materials — such as machine operators and assemblers — whereas workers in the services group perform personal services — such as security guards, estheticians and babysitters. In the following discussions, we define knowledge workers as “more-skilled” or “skilled” and the remaining three categories of workers — data, goods and services — as “less-skilled” or “unskilled”.

Trends in Skill Intensity at the Aggregate Level: 1981–94

Table 1 presents evidence at the aggregate level on trends in employment growth (total hours worked) for *NOC-based* skill levels from 1981 to 1994. Three observations emerge. First, skill requirements in Canadian industries rose between 1981 and 1994 — the share of more-skilled workers rose from 35.5 percent in 1981 to 41.4 percent in 1994 (0.74 percentage point per year). While total employment grew at an average annual rate of about 1.7 percent, the employment of more-skilled workers grew at a rate of 2.9 percent per year over this period. Second, the employment share of managers increased at a much faster rate than that of other groups of skilled workers. Third, while both the manufacturing sector and the service sector have become more skill-intensive over time, the rise in skill intensity is more pronounced in the service sector.

An alternative measure of changes in the demand for more-skilled labour is the change in their share of the wage bill.[8] Table 2 shows the fraction of the wage bill going to more-skilled labour rather than the fraction of employment. It shows the same pattern as noted in Table 1 — a gradual increase in skilled workers’ share of the wage bill.

Table 3 and 4 show the relative employment and wage bill shares of workers by skill level using the Wolff and Baumol (1989) classification scheme. Three familiar messages emerge. First, the share of more-skilled workers (i.e., the knowledge workers) in the total wage bill and employment increased in both manufacturing and services over the 1981–94 period. Second, the share of knowledge workers grew at a faster rate in services than in manufacturing. Third, goods workers accounted for an increasingly smaller share of the total wage bill and employment over this period.

Relative Wage Performance: 1981–94

The data show that wage differentials between more-skilled and less-skilled workers remained stable or fell slightly over this period (Table 5). This is striking in light of the fact that the ratio of skilled to unskilled workers employed rose between 1981 and 1994. In a simple supply and demand framework of the labour market, one obvious explanation for this occurrence is that both the relative supply of and demand for skilled workers must have increased. All other things held constant, the relative wage of skilled labour should remain unchanged if the demand for skilled labour grows at the same rate as the supply of skilled labour. Obviously, an underlying assumption in this framework is that workers with different levels of skills are not perfect substitutes in production.

Clearly, the 1980s and early 1990s saw an upskilling in the labour force, as demonstrated by changes in the educational level of workers (Freeman and Needels, 1993; Murphy, Riddell and Romer, 1997). Table 6 documents the shifts in the educational composition of the Canadian labour force from 1981 to 1994. The educational attainment of the labour force has increased rapidly over this period.

There is a dramatic decline in the share workers with a high school degree or less and an almost two-fold increase in the share of those with a postsecondary or university degree.

The following major conclusions emerge at the aggregate level:

(1) the relative supply of more-skilled workers increased over this period;

(2) the relative wages of skilled workers remained stable or fell slightly;

(3) thus, we infer that the relative demand for more-skilled workers rose.

In contrast, in the U.S. labour market the relative wages of skilled workers rose as the relative demand for skilled labour grew more than the relative supply in the 1980s (e.g., Lawrence and Slaughter, 1993; Berman, Bound and Griliches, 1994; Autor, Katz and Krueger, 1997).

Skill Changes at the Industry Level: 1981–94

Table 7 presents, for both measures of skills, the share of total employment occupied by skilled workers in each industry. Let us first consider the NOC-based definition of skilled workers. With almost 80 percent of skilled workers in 1994, the electrical products manufacturing industry was the most skill-intensive industry in Canada, largely exceeding the 41.4 percent average for all industries in our sample. The insurance industry follows with 78.1 percent of skilled workers. Most labour-intensive industries in the manufacturing sector — leather, textile, clothing, wood, furniture and fixtures — have a below-average share of skilled workers.

One of the remarkable features of most Canadian industries during the 1981–94 period was the rise in skill intensity[9] that occurred in almost every industry. The rise in skill intensity is most notable in scale-based manufacturing industries such as printing, publishing and allied, and machinery, and in services such as storage, retail trade, and amusement and recreation.

The same pattern emerges for knowledge workers. We find that skill intensity rose in most industries during the 1981–94 period. Most service industries experienced an above-average increase in skill intensity (Table 7). However, many scale-based manufacturing industries such as rubber and plastics, furniture and fixtures, machinery, and miscellaneous manufacturing also experienced an above-average rise in skill intensity.

The key question then is why has the demand for labour shifted towards more-skilled workers in the 1980s and early 1990s? As discussed earlier in the paper, two major reasons have been put forward to explain such a shift. One explanation postulates that the shift away from unskilled workers is mainly driven by technological change that is "biased" toward the use of more-skilled workers (Berman, Bound and Griliches, 1994; Bound and Johnson, 1992). The second explanation argues that increased trade with developing countries has caused a shift in production from less-skilled, import-sensitive sectors to more-skilled, export-intensive sectors (Wood, 1994; Murphy and Welch, 1992).[10]

In the next two sections, we examine whether technological change that saves less-skilled labour is the most likely explanation for the shift in demand toward more-skilled workers.

Table 1
Level and Change in the Skill Composition of Employment, 1981–94
NOC Skill Classification

	Annualized Growth (%)	Share of Total Hours Worked by Type of Worker (%)							
All Industries	**1981–94**	**1981**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**
Skilled*	2.87	35.50	39.74	39.61	39.74	40.05	40.04	41.45	41.43
Managers	7.01	6.00	10.92	10.74	10.85	10.98	10.83	11.58	12.01
Professional	4.12	7.07	7.64	7.76	7.81	8.11	7.78	9.44	9.71
Technical	0.69	22.42	21.18	21.10	21.08	20.97	21.42	20.43	19.71
Unskilled**	0.94	64.50	60.26	60.39	60.26	59.95	59.96	58.55	58.57
Total	1.68	100	100	100	100	100	100	100	100
Manufacturing									
Skilled*	1.16	29.37	31.65	30.11	29.66	30.56	29.58	33.62	34.13
Managers	3.70	6.44	8.45	7.87	7.59	7.87	7.55	9.53	10.42
Professional	1.76	6.26	6.40	6.71	6.32	7.15	6.81	8.38	7.87
Technical	-0.39	16.67	16.80	15.53	15.75	15.54	15.22	15.72	15.84
Unskilled**	-0.54	70.63	68.35	69.89	70.34	69.44	70.42	66.38	65.87
Total	-0.00	100	100	100	100	100	100	100	100
Services									
Skilled*	3.45	38.66	43.09	43.44	43.9	43.87	44.09	44.37	44.18
Managers	8.42	5.78	11.94	11.90	12.19	12.23	12.10	12.35	12.61
Professional	4.95	7.49	8.15	8.19	8.42	8.49	8.16	9.84	10.40
Technical	1.03	25.38	23.00	23.35	23.28	23.15	23.82	22.18	21.17
Unskilled**	1.70	61.34	56.91	56.56	56.10	56.13	55.91	55.63	55.82
Total	2.42	100	100	100	100	100	100	100	100

* The "skilled" category includes managers, professional occupations and technical skilled occupations (for details see Table A1 in the Appendix).

** The "unskilled" category includes intermediate occupations and unskilled occupations (for details see Table A1 in the Appendix).

Table 2
Level and Change in the Skill Composition of the Wage Bill, 1981–94
NOC Skill Classification

	Annualized Growth (%)	**Share of the Wage Bill by Type of Worker (%)**							
All Industries	**1981–94**	**1981**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**
Skilled*	7.73	42.61	46.68	46.52	45.59	46.72	46.75	49.41	49.46
Managers	11.10	8.70	13.32	13.22	12.76	13.15	12.95	14.99	15.65
Professional	8.62	9.67	9.83	10.11	9.83	10.39	9.92	12.28	12.59
Technical	5.56	24.25	23.54	23.19	23.00	23.18	23.88	22.15	21.22
Unskilled**	5.61	57.39	53.32	53.48	54.41	53.28	53.25	50.59	50.54
Total	6.58	100	100	100	100	100	100	100	100
Manufacturing									
Skilled*	6.63	34.43	37.37	36.29	34.45	35.5	34.71	41.26	40.68
Managers	9.26	8.59	11.82	11.65	10.42	10.90	10.22	13.31	14.27
Professional	6.44	8.38	7.91	8.53	8.02	8.70	8.40	10.71	9.66
Technical	5.03	17.46	17.64	16.11	16.01	15.90	16.09	17.24	16.75
Unskilled**	4.58	65.57	62.63	63.71	65.55	64.50	65.29	58.74	59.32
Total	5.35	100	100	100	100	100	100	100	100
Services									
Skilled*	8.14	47.32	50.64	50.8	50.26	51.42	51.53	53.12	53.41
Managers	11.97	8.76	13.95	13.88	13.74	14.10	14.03	15.75	16.27
Professional	9.45	10.40	10.65	10.77	10.59	11.10	10.53	12.99	13.91
Technical	5.73	28.15	26.04	26.16	25.93	26.23	26.97	24.38	23.23
Unskilled**	6.26	52.68	49.36	49.20	49.74	48.58	48.47	46.88	46.59
Total	7.21	100	100	100	100	100	100	100	100

* The “skilled” category includes managers, professional occupations and technical skilled occupations (for details see Table A1 in the Appendix).

** The “unskilled” category includes intermediate occupations and unskilled occupations (for details see Table A1 in the Appendix).

Table 3
Level and Change in the Skill Composition of Employment, 1981–94
Wolff & Baumol Skill Classification

	Annualized Growth (%)	Share of Total Hours Worked by Type of Worker (%)							
All Industries	**1981–94**	**1981**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**
Knowledge	5.12	9.51	12.32	12.30	12.71	12.96	12.69	14.39	14.86
Data	1.83	37.50	37.20	37.20	37.48	37.42	37.98	37.63	38.21
Services	1.50	11.23	10.93	11.15	10.56	10.42	10.61	11.56	10.97
Goods	0.53	41.76	39.55	39.35	39.25	39.21	38.72	36.42	35.96
Total	1.68	100	100	100	100	100	100	100	100
Manufacturing									
Knowledge	2.38	10.25	10.80	10.61	10.45	11.02	10.71	13.44	13.97
Data	0.53	20.04	19.83	19.40	19.90	19.78	20.96	21.33	21.49
Services	-0.15	2.46	1.79	1.83	1.70	1.92	1.97	2.12	2.42
Goods	-0.61	67.25	67.59	68.15	67.95	67.28	66.37	63.11	62.13
Total	-0.00	100	100	100	100	100	100	100	100
Services									
Knowledge	6.34	9.13	12.95	12.97	13.64	13.74	13.46	14.74	15.20
Data	2.08	46.49	44.41	44.38	44.73	44.52	44.57	43.70	44.49
Services	1.62	15.74	14.72	14.91	14.21	13.84	13.96	15.07	14.19
Goods	1.72	28.64	27.92	27.73	27.42	27.90	28.01	26.49	26.13
Total	2.42	100	100	100	100	100	100	100	100

Table 4
Level and Change in the Skill Composition of the Wage Bill, 1981–94
Wolff & Baumol Skill Classification

	Annualized Growth (%)	**Share of Wage Bill by Type of Worker (%)**							
All Industries	**1981–94**	**1981**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**
Knowledge	9.59	13.13	15.44	15.46	15.53	15.99	15.65	18.56	19.40
Data	6.83	35.45	35.95	35.68	35.97	35.78	36.14	36.07	36.62
Services	5.77	7.47	7.91	8.29	8.42	7.70	8.07	7.02	6.72
Goods	5.31	43.96	40.69	40.57	40.08	40.54	40.15	38.34	37.26
Total	6.58	100	100	100	100	100	100	100	100
Manufacturing									
Knowledge	7.64	13.35	13.98	14.08	13.39	13.87	13.44	17.59	17.98
Data	6.23	20.05	21.06	20.43	21.60	20.96	22.05	23.01	22.48
Services	5.06	2.23	1.66	1.80	1.51	1.70	1.75	1.74	2.14
Goods	4.47	64.37	63.31	63.70	63.50	63.47	62.76	57.66	57.39
Total	5.35	100	100	100	100	100	100	100	100
Services									
Knowledge	10.54	13.00	16.07	16.04	16.43	16.87	16.52	19.01	20.04
Data	6.98	44.29	42.28	42.07	42.00	41.99	41.74	42.02	43.00
Services	5.85	10.48	10.57	11.02	11.32	10.21	10.57	9.43	8.78
Goods	6.18	32.23	31.08	30.88	30.25	30.93	31.16	29.55	28.18
Total	7.21	100	100	100	100	100	100	100	100

Table 5
Real Wage Rates in 1992 Dollars by Skill Level, 1981–94

	Annualized Growth (%)	Real Wage Rates (Dollar per Hour)							
	1981–94	**1981**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**
NOC–based Skill Levels									
Skilled*	0.63	16.38	19.48	20.31	20.66	20.58	19.91	17.27	17.78
Managers	-0.14	19.78	20.22	21.28	21.18	21.13	20.38	18.74	19.42
Professional	0.28	18.64	21.33	22.52	22.67	22.61	21.74	18.84	19.32
Technical	0.64	14.75	18.41	19.01	19.65	19.51	19.00	15.71	16.04
Unskilled**	0.45	12.14	14.66	15.31	16.26	15.69	15.14	12.51	12.86
Wolff & Baumol Skill Levels									
Knowledge	0.24	18.85	20.77	21.74	22.00	21.76	21.03	18.69	19.45
All Others***	0.57	13.11	15.98	16.67	17.43	17.03	16.47	13.78	14.11
Data	0.78	12.90	16.02	16.59	17.29	16.88	16.23	13.89	14.28
Services	0.04	9.07	12.00	12.87	14.36	13.03	12.96	8.80	9.12
Goods	0.56	14.36	17.06	17.83	18.38	18.25	17.68	15.26	15.44

* The “skilled” category includes managers, professional occupations and technical skilled occupations (for details see Table A1 in the Appendix).

** The “unskilled” category includes intermediate occupations and unskilled occupations (for details see Table A1 in the Appendix).

*** The “all others” category includes data, services and goods workers (for details see Table A2 in the Appendix).

Table 6
Labour Force Composition by Education, 1981–94

Education Level	Average Annual Growth Rate* (%)	Total Percent Change 1981–94 (%)
0 – 8 years	-5.9	-52.0
Some high school and high school completed	-1.1	-12.7
Some post-secondary	2.1	27.9
Post-secondary	9.4	193.4
University	5.1	82.7
Total	1.6	20.3

* Compound average annual growth rates.
Source: Based on data from the Labour Force Survey, Statistics Canada.

Table 7
Employment Share of Skilled Workers by Industry

Industry	NOC-based Skilled Workers			Knowledge Workers		
	1981 (%)	1994 (%)	Change (% point)	1981 (%)	1994 (%)	Change (%point)
Food and Beverage	23.84	26.81	2.97	7.50	12.04	4.54
Tobacco Products	15.88	8.65	-7.22	2.93	8.65	5.73
Rubber and Plastics	25.13	29.50	4.37	9.48	16.58	7.10
Leather	3.60	14.00	10.39	1.47	7.00	5.53
Textiles	25.56	10.95	-14.61	9.61	2.93	-6.67
Clothing	5.74	5.73	-0.00	2.53	1.93	-0.60
Wood	19.16	20.15	0.99	3.18	5.96	2.78
Furniture and Fixtures	15.30	16.05	0.75	3.67	12.01	8.33
Paper and Allied Products	27.56	36.84	9.27	9.10	13.95	4.85
Printing, Publishing & Allied	29.50	43.88	14.38	10.90	15.39	4.49
Primary Metals	28.62	30.96	2.33	9.02	13.21	4.19
Metal Fabricating	24.07	16.19	-7.88	10.01	8.34	-1.67
Machinery Industries	34.98	51.08	16.10	15.43	21.67	6.24
Transportation Equipment	29.99	35.75	5.76	9.76	15.19	5.42
Electrical Products	71.58	79.92	8.33	18.54	23.31	4.77
Non-metallic Minerals	21.52	31.04	9.52	9.43	9.17	-0.25
Petroleum & Coal Products	56.71	49.33	-7.38	36.84	36.77	-0.07
Chemicals & Chemical Products	44.59	45.71	1.12	23.21	27.88	4.67
Miscellaneous Manufacturing	26.29	34.33	8.04	8.44	14.01	5.57
Transportation	20.79	20.07	-0.72	5.18	5.69	0.51
Storage	19.25	43.07	23.82	6.38	18.80	12.43
Communication	61.31	48.70	-12.61	17.60	19.80	2.19
Electric Power, Gas & Water	46.14	51.92	5.77	8.51	19.62	11.11
Wholesale	31.59	39.58	7.99	8.44	15.67	7.23
Retail	23.14	36.23	13.09	2.65	9.86	7.21
Finance	53.81	58.68	4.87	14.71	24.01	9.30
Insurance	75.65	78.14	2.50	15.68	23.77	8.10
Amusement & Recreation	39.91	55.28	15.38	16.82	24.19	7.37
Other Services	49.81	57.79	7.99	23.78	27.46	3.68
Accommodation & Food Services	4.16	11.81	7.65	1.33	4.93	3.60
Construction	74.99	69.82	-5.17	5.04	7.44	2.40

3. SHIFT-SHARE ANALYSIS

Berman, Bound and Griliches (1994) argue that explanations based on the increase in international trade are likely to involve shifts in production *between* industries from those intensive in production workers (less-skilled) to those intensive in nonproduction workers (more-skilled). In contrast, broad skill-biased technological change that favours more-skilled workers would shift the skill composition of labour demand *within* industries.[11] A decomposition of the increase in the more-skilled share of employment and of the wage bill into the between-industry and within-industry components can help illustrate the potential importance of these alternative sources of shifts in labour demand.

Using the methodology of Berman, Bound and Griliches (1994), we decompose the change in the proportion of skilled workers in aggregate employment in a given period, ΔS , into a term reflecting reallocation of employment *between* industries and a term reflecting changes in proportions *within* industries as follows:

$$(1) \qquad \Delta S = \sum_i \bar{S}_i \Delta P_i + \sum_i \bar{P}_i \Delta S_i$$

where S_i is the share of skilled workers in industry i and P_i is the share of employment in industry i for industries $i = 1,2,\ldots\ldots,N$. Δ signifies change over a given period and a bar over a variable denotes a mean over time.

The first term on the right hand side of the equation reflects the change in the aggregate proportion of skilled workers attributable to changes in employment shares *between* industries with different proportions of skilled workers. The second term reflects the change in the aggregate proportion attributable to changes in the proportion of skilled workers *within* each industry.

For the NOC-based skill classification, Table 8 reports between-industry and within-industry decompositions of both the employment share and the wage bill share of more-skilled workers from 1981 to 1994. It shows that within-industry changes account for most of the overall change in the skilled workers share of employment and of the wage bill. For example, of the 0.456 percentage point per annum increase in the skilled worker share of employment between 1981 and 1994, the within-industry component accounts for 0.405 percentage point, or 89 percent, and the between-industry component accounts for 0.051 percentage point, or 11 percent. The pattern is somewhat different in manufacturing and in services. The rate of within-industry upskilling in services exceeds that in manufacturing. The same pattern emerges from the wage bill share calculations.[12]

Table 9 displays the between-industry and within-industry decompositions of the change in the proportion of knowledge workers in employment and in the share of the wage bill. The findings are similar to those reported above for the NOC skill classification. One difference worth noting is that within-industry shifts play a relatively larger role in manufacturing than in the service sector.

Tables A3 and A4 (in the Appendix) present the shift-share decompositions of the change in the wage bill share of more-skilled workers for each of the 31 manufacturing and services industries. Two striking features deserve a mention. First, the within-industry component is positive for most industries, suggesting that the increase in skill intensity is pervasive across industries. Second, negative signs for the between-industry component in manufacturing industries suggest that upskilling occurs because there is a shift from the manufacturing to the service sector.

On the basis of the findings indicating a rise in the within-sector demand for skills, Berman, Bound and Griliches (1994) claim that this is consistent with biased technological change playing a dominant role in explaining the increased share of skilled employment. They argue against the view that increased international trade with developing countries is responsible for the decreased demand of low-skilled workers; they maintain that trade should induce employment shifts toward relatively high-skill industries, and away from low-skill ones, rather than overall upskilling within each industry.

Though suggestive of the importance of technological change in explaining the shift toward relatively skilled workers, the decomposition results themselves do not constitute direct and convincing evidence of a skill-biased technical change in the absence of observable measures of technological change (Baldwin 1995, Machin, Ryan and Van Reenen 1996).

In the next section, we explore the relationship between skill-upgrading (the shift towards more-skilled workers) and various observable measures of technological change using industry-level regressions.

Table 8
Decomposition of Changes in the Wage-Bill Share and Employment Share of Skilled Workers, 1981–94
NOC Skill Classification

Wage Bill Shares				
	Total Change	**Between Industry**	**Within Industry**	**Within as a % of Total Change**
	(percentage points)			
All Industries	6.84	1.26	5.58	81.55
Manufacturing	6.26	0.74	5.52	88.24
Services	6.10	0.45	5.65	92.70
Shares of Total Hours				
	Total Change	**Between Industry**	**Within Industry**	**Within as % of Total Change**
	(percentage points)			
All Industries	5.93	0.67	5.26	88.69
Manufacturing	4.76	0.61	4.15	87.22
Services	5.52	-0.25	5.77	104.47

Table 9
Decomposition of Changes in the Wage-Bill Share and Employment Share of Knowledge Workers, 1981–94
Wolff & Baumol Skill Classification

Wage Bill Shares				
	Total Change	**Between Industry**	**Within Industry**	**Within as a % of Total Change**
	(percentage points)			
All Industries	6.27	1.07	5.20	82.89
Manufacturing	4.63	-0.03	4.66	100.67
Services	7.04	1.55	5.48	77.91
Shares of Total Hours				
	Total Change	**Between Industry**	**Within Industry**	**Within as % of Total Change**
	(percentage points)			
All Industries	5.35	0.56	4.80	89.60
Manufacturing	3.72	0.05	3.67	98.61
Services	6.07	0.77	5.30	87.31

4. SKILL UPGRADING AND TECHNOLOGY: INTER-INDUSTRY EVIDENCE

Empirical Framework

The findings from the shift-share analysis show that most of the rise in employment and wage-bill shares of more-skilled workers since 1981 has occurred *within* industries. To further understand the determinants of within-industry shifts towards more-skilled workers, we relate the employment share and wage-bill share of more-skilled workers across industries to industry-level measures of technology. Following Berman, Bound and Griliches (1994), we specify a restricted variable cost function for industry *i* in year *t*, with capital as a fixed factor input:

$$C(\log W_{it}^{s}, \log W_{it}^{ns}, \log K_{it}, \log Y_{it}, TECH_{it}, T)$$

We can derive from the cost function the wage bill share equation for skilled workers.

(2) $$S_{it} = b_{o} + b_{1}\log K_{it} + b_{2}\log Y_{it} + b_{3}TECH_{it} + b_{4}T + b_{5}\log(W_{it}^{s} / W_{it}^{ns})$$

where for industry *i*, *S* is the share of relatively skilled workers in the total wage bill, *K* is the capital stock, *Y* represents value added, *TECH* is an index of technology measures, *T* is a time trend representing technological change that is not captured by the technology index *TECH*, and W^{s} and W^{ns} represent the wages of skilled and unskilled workers.[13]

The equation we estimate for the panel of industries is the stochastic form of equation (2) that includes "fixed industry effects":

(3) $$S_{it} = b_{i} + b_{1}\log K_{it} + b_{2}\log Y_{it} + b_{3}\log TECH_{it} + b_{4}T + b_{5}\log(W_{it}^{s} / W_{it}^{ns}) + e_{it}$$

We include fixed industry effects, b_i, to control for any unobserved heterogeneity across industries in unmeasured determinants of *S*. In this fixed effect model, estimated coefficients of the technology index reveal whether an industry, which experienced above-average technological progress, also experienced an above-average increase in the share of skilled workers over a given period. We also estimate an alternative version of equation (3) using the employment share of skilled workers as the dependent variable.

Measures of Technological Change

Many recent studies examine the relationship between changes in workforce skill and changes in industry capital intensity and industry-level investment in computer equipment (e.g., Autor, Katz and Krueger, 1997; Machin, Ryan and Van Reenen, 1996; Berman, Bound and Griliches, 1994; Berndt, Morrison and Rosenblum, 1992). All of these studies find evidence of capital-skill complementarity and a strong positive correlation between the level of computer investment in an industry and changes in the skill composition of the workforce in the industry.

The diffusion of computers and computer-based technologies is a prime suspect for the recent widespread technological change affecting the content of work and skill requirements. The results from the 1995

Working With Technology Survey (WWTS III), which collected technology and human resource data covering the 1992–94 period from 263 Canadian establishments, confirm that the occupational and skill structure appears to be moving definitely towards employment of highly skilled workers and away from employment of unskilled workers (McMullen, 1996). However, our analysis does not include these variables due to the unavailability of time series data on computer usage and computer technologies by industry.

Baldwin, Gray and Johnson (1997) use several Canadian manufacturing establishment-level surveys to find much more direct evidence on whether technology requires more-skilled workers. They find that, depending on the technology, 47 to 59 percent of firms adopting new technologies reported increased skill requirements, while only a small number of firms reported reduced skill requirements. Dunne and Schmitz (1995) and Siegel (1998) use plant-level data and find that plants that use more factory automation technologies employ more educated workers. Finally, Doms, Dunne and Troske (1997), using a cross-sectional analysis, find that plants that use a large number of new technologies employ more educated workers and relatively more managers, professionals, and precision-craft workers, and pay higher wages. However, their longitudinal analysis shows little correlation between skill upgrading and the adoption of new technologies.

In this paper, we combine data on skill measures by industry with four industry-level measures of technology: the stock of research and development (R&D), the stock of patents used by industry, total factor productivity, and the age of the capital stock.[14] These industry-level technology indicators are likely to capture variations in the rate of technological change across industries. These various measures of technology are also likely to capture variations in the nature of industry's technology. However, each measure has its advantages and disadvantages. For example, the stock of R&D and the stock of patents are input-based measures of technology. A common criticism of R&D is that it is not a good measure of technology. However, R&D can be considered a broader measure of innovation — an investment in human capital devoted to perform knowledge-based innovation. The stock of patents has the advantage of being a direct measure of technology diffusion. However, a major disadvantage of this measure is that the likelihood of an innovation being patented varies across industries and over time.[15]

Total factor productivity (TFP) — an output-based measure of technology — is defined as output produced per composite unit of all inputs. Though mainly reflecting technological change, a change in total factor productivity may also result from various factors such as increasing returns to scale, changes in the organization of production, or a mismeasurement related to the quality of capital and labour inputs. An important disadvantage associated with total factor productivity is the mismeasurement problem resulting mainly from the difficulty of measuring output in the service sector (Baily and Gordon, 1988).

While the R&D stock, the patent stock and total factor productivity are familiar measures of technology, the age of the capital stock is somewhat less familiar. To the extent that technology is embodied in capital goods, the age of gross capital stock serves as a proxy for technology.[16] The vintage effect or the embodiment hypothesis suggests that new capital is more productive than older capital because it is more likely to embody best-practice technologies (Wolff, 1996*b*; Gera, Gu and Lee, 1999). Bartel and Lichtenberg (1987) found a strong negative association between the age of the capital stock and the employment share of highly educated workers among U.S. manufacturing industries for the years 1960, 1970 and 1980. They interpret this as evidence in support of the hypothesis that the introduction of new technologies increases the relative demand for educated workers as they have a comparative advantage with respect to learning and implementing new technologies.

We compute a correlation matrix of the four measures of technology used in our analysis (Table A5 in the Appendix). The correlation matrix shows that no two measures are highly correlated, suggesting that there is no redundancy in using all of them in our analysis. The correlations between the different measures range from 0.02 to 0.3, which seems consistent with the view, as argued by Bartel and Sicherman (1997), that each proxy is likely to capture a different aspect of technological change.

Before turning to our empirical analysis, we wish to make two points. First, we examine the relationship between the relative demand for skilled workers and technology across industries using a fixed effect model and specify our dependent variable in level form. In contrast, Berman, Bound and Griliches (1994) and Autor, Katz and Kruger (1997) employ the first-difference form to examine this relationship using *changes* over time in the demand for skilled workers and the industry's rate of technological change. Bartel and Sicherman (1997) argue that year-to-year variations in these measures are likely to conceal significant measurement errors and would fail to capture variations across industries in the true changes in the rate of technological change.[17]

Second, data on the patent stock, the R&D stock, and total factor productivity by industry are not available for the early 1990s. Our regression analysis is therefore restricted to the periods 1981 and 1986 through 1990.[18]

Trends in the wage-bill shares of skilled workers, and the log of the growth rates of technology measures for the sample industries are reported in Table 10. Column (1) shows the annual change in the share of the total wage bill for the NOC skilled workers. Column (2) shows changes in the wage-bill share of knowledge workers. Data in both columns show what we have seen already: the share of wages paid to more-skilled workers rose in most industries over the 1981–94 period. The remaining columns show the annual growth in the capital stock, real output and various measures of technology over the 1981–90 period. The following messages emerge: (1) the capital stock increased in all industries with the exception of textiles, and non-metallic minerals; (2) most industries experienced output growth during 1981–90 period, in particular electrical products, transportation equipment, communication, insurance, and wholesale trade industries recorded relatively high growth rates of output; (3) R&D increased in all industries, except the tobacco products industry; (4) the stock of patent usage dropped in most industries; (5) the average age of the capital stock declined in most industries suggesting increases in new capital stock; and (6) many industries recorded negative TFP growth rates over this period. Most notable are the labour-intensive manufacturing industries such as food and beverage, tobacco products, clothing, and furniture and fixtures. In the service sector, the insurance industry recorded the highest annual rate of TFP growth (2.25 percent), while finance experienced the lowest TFP growth (-2.08 percent).

Raw Correlation

Figure 1 shows the cross-industry correlation between the annual change in the wage-bill share of NOC skilled workers and the rate of change of various measures of technology in the 1980s and early 1990s.[19] Figure 2 plots the same relationships for knowledge workers. Figures 1a-1c and 2a-2c show a positive relationship between the rise in skill intensity (measured by the increase in the wage bill-share of NOC skilled workers or that of knowledge workers) and input-based measures of technological change.[20] As implied by the skill-biased technological change hypothesis, the change in the wage-bill share of skilled workers is positively associated with the rate of change in R&D stock and patent stock, and is negatively associated with the change in the age of the capital stock. In most cases, these relationships are statistically significant at the 5 percent level. The negative relationship between the share of the wage bill and the age of the capital stock confirms the findings of Bartel and Lichtenberg (1987) that workers in industries with a younger capital stock have more human capital.

Figures 1d and 2d show a negative correlation between the growth of total factor productivity and change in skill intensity. However, the coefficient is not statistically significant.

In sum, on the basis of the input-based measures of technological change — R&D, use of patents, age of the capital stock – the correlations suggest that biased technological change within industries was a key driving force behind the growth in demand for skilled workers. In contrast, output-based measures of technological change (TFP growth) do not seem to be positively correlated with increases in the relative demand for skilled workers.[21] We now turn to a regression analysis to examine the impact of technological change on the demand for skilled workers.

Regression Results

Estimates of the Wage-Bill Share Equation — NOC Skilled Workers

The regression analysis is performed on pooled cross-section time-series data set comprising 29 industries and covering the 1981–90 period. The dependent variable is the share of the wage bill for NOC skilled workers. The estimation results for equation (3) are presented in Table 11 (a). Specification (1) includes the logarithms of the real capital stock, real output, relative wages of skilled workers, and time trend as independent variables. Industry dummies are introduced to control for fixed industry effects. The positive coefficient on the time trend variable shows that the skilled workers' share of the wage bill increased over time across industries. The estimated coefficient of the real capital stock variable has a positive sign but does not show a significant relationship with the skilled workers' share of wage bill. Both the capital and output variables explain very little skill upgrading and do not provide strong support for overall capital-skill complementarity. The estimated coefficient of the relative wage term is positive and statistically significant at the 1 percent level. Applying the wage-bill share of skilled workers in 1994 (41.43%), we find that skilled and unskilled workers are substitutes and that the elasticity of substitution equals 0.20.

In the next four specifications, we introduce alternative indicators of technology. Specification (2) uses the log of the R&D capital stock while specification (3) uses the log of the patent stock, specification (4) uses the average age of the capital stock and specification (5) uses the log of TFP.

In specification (2), the R&D stock has the expected positive sign and is significant at the 10 percent level. The coefficient on the R&D variable suggests that, on average, a 10 percent increase in the R&D capital stock across industries increases the share of skilled workers by 0.1 percentage points per year. These results indicate that the R&D stock has a significant impact on skill intensity within industries. Using the average R&D capital stock across industries, we calculate that this measure of technology accounted for 1.2 percentage points, or 30 percent, of the total increase in the wage share of skilled workers over the 1981–90 period.

Another technology indicator, the stock of patents used by an industry, is included in our share equation in specification (3). The variable shows positive and significant effects. The coefficient suggests that, on average, a 1 percent increase in the stock of patents used would increase the share of skilled workers by about 0.04 percentage point across industries. However, this variable explains very little of the skill upgrading observed over this period.

Specification (4) reports on regression using the average age of the capital stock as an alternative indicator of technology. The variable serves as a proxy for capital-embodied technical change (i.e., newer capital embodies the latest technologies). Following Bartel and Lichtenberg (1987), our hypothesis is that skilled workers have a comparative advantage with respect to the adoption of an innovation; that is, the process of adjustment to (the implementation of) new technology is skilled-labour-using. Under this assumption, a negative correlation should be observed between the share of skilled workers and the average age of capital. Our findings of a negative and significant coefficient for the age of the capital stock provide rather strong support for the hypothesis that capital-embodied technical change has been an important contributor to within-industry skill upgrading. Our calculations show that the age of the capital stock accounted for 2.5 percentage points, or 62 percent, of the total shift in the demand for skilled workers over the 1981–90 period. While we do not observe general capital-skill complementarity in our data, the coefficient of this variable suggests younger capital-skill complementarity.

In specification (5), we examine the effect of total factor productivity on skill intensity. The estimated coefficient of the TFP variable is not statistically significant. We suspect that this result may be due to the service industries that experience slower TFP growth relative to manufacturing despite showing a higher increase in skill intensity. It may also reflect the general problem of mismeasurement of output in service industries.[22]

In specification (6), we include all the technology indicators in the same equation. The coefficients of the R&D capital stock, the patent stock and the age of the capital stock remain significant. We find that the R&D capital stock and the age of the capital stock together account for almost all of the shift toward skilled labour, while the patent stock variable is not a contributing factor to skill upgrading. These findings clearly demonstrate that within-industry skill upgrading has occurred both in those industries that invested heavily in new capital during the 1980s and in those that accumulated R&D capital.[23]

Appendix Table A6(a) presents the estimation results excluding the relative wage terms. As argued by Berman, Bound and Griliches (1994), the industry specific relative wages are likely to be endogenous. Overall, the results are qualitatively similar and the parameter estimates are robust to the exclusion of the relative wage terms.

Finally, we also examine whether the impact of skilled-biased technological change on skill upgrading has been different across service and manufacturing industries. We do so by introducing an interaction term between technology measures and manufacturing dummies across all specifications. The results, although not reported in Table 11(a), show that the coefficient of this variable is not significantly different from zero in any of the specifications. These findings do not provide support for the hypothesis that the impact of biased-technological change on skill upgrading has been different across the manufacturing and service sectors.

Estimates of the Employment Share Equation —NOC Skilled Workers

Now we estimate equation (3) using the employment share of (NOC) skilled workers as the dependent variable. Table 11(b) presents regression results for all six specifications. The direction of the results seems consistent with those discussed above using the wage-bill share equation.

Both the R&D capital stock and the stock of patents used have a significant positive effect on skill intensity across industries in most specifications (specifications 3 and 6). The coefficient on the age of the capital stock is again negative and significant at the 1 percent level in specification (4), although in specification (6) it loses significance somewhat. The TFP variable picks up statistical significance in specification (6). The coefficient of the relative wage terms is statistically significant in almost all specifications and its negative sign suggests that skilled and unskilled workers are substitutes.

As shown in Appendix Table A6(b), the results are again robust to the exclusion of relative wage terms. Overall, the results confirm a significant effect of technological change on skill upgrading across Canadian industries in the 1980s and early 1990s.

Estimates of the Wage-Bill Share Equation — Knowledge Workers

The above discussion shows that skill upgrading across Canadian industries is strongly and positively related to technological change. To examine the robustness of our results, we re-estimate equation (3) using knowledge workers' share of the wage bill as our measure of skill intensity.

The estimation results for all six specifications are presented in Table 12(a). The estimates for specification (2) show a significant positive effect of the R&D capital stock on skill intensity. Specification (6) further confirms the robustness of this variable. Based on the coefficient of R&D in specification (6), our calculations show that the R&D capital stock increased the demand for knowledge workers by about 0.12 percentage point per year, or 44 percent of the total increase over the 1981–90 period. In specification (3), the patent variable shows a strong correlation with skill intensity. But, in specification (6) this relationship becomes less significant. The age of the capital stock is negatively and significantly related to skill intensity in specification (6), but is somewhat less significant in specification (4). Our calculations based on specification (6) show that this variable explains about 50 percent of total skill upgrading over the 1981–90 period. We also find that the TFP variable is now positively related to the wage-bill share of knowledge workers and is significant at the 10 percent level.

Appendix Table 7(a) presents the same specifications excluding the relative wage variable due to possible endogeneity of the variable. The results are similar and robust to the exclusion of the relative wage terms.

In summary, the estimates presented in Table 12(a) confirm the findings shown in Table 11, that is, technological change variables explain almost all the skill upgrading in Canadian industries from 1981 to 1990.

Estimates of the Employment Share Equation — Knowledge Workers

Table 12(b) presents employment share regressions for knowledge workers over the 1981–90 period. All coefficients are closely comparable to those presented in Table 12(a). Both specifications (2) and (6) indicate that R&D has a significant impact on skill intensity. Estimates from specification (3) and (6) confirm the significant impact of patents on the shift in demand for knowledge workers. The age of the capital stock variable has negative sign, and is statistically significant at the 10 percent level in specification (6). The TFP coefficient in specification (6) shows a positive and significant impact on the shift toward increased demand for knowledge workers.

Overall, our results provide strong support for the notion that biased technological change has been the main driving force behind skill upgrading in Canadian industries during the 1980s and early 1990s.

Figure 1
Skill Upgrading and Technological Change: NOC Skill Classification

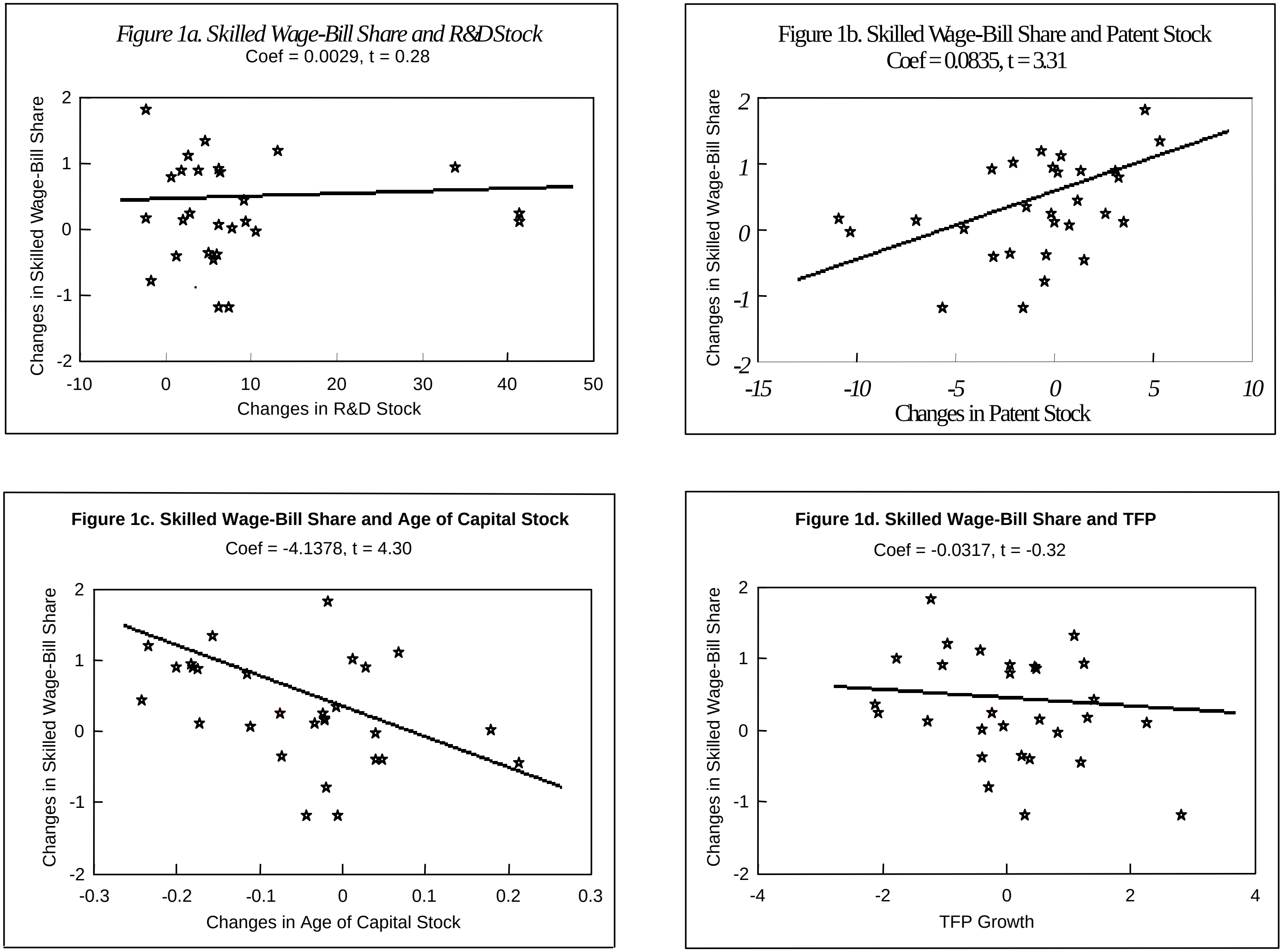

Figure 2

Skill Upgrading and Technological Change: Osberg, Wolff and Baumol Skill Classification

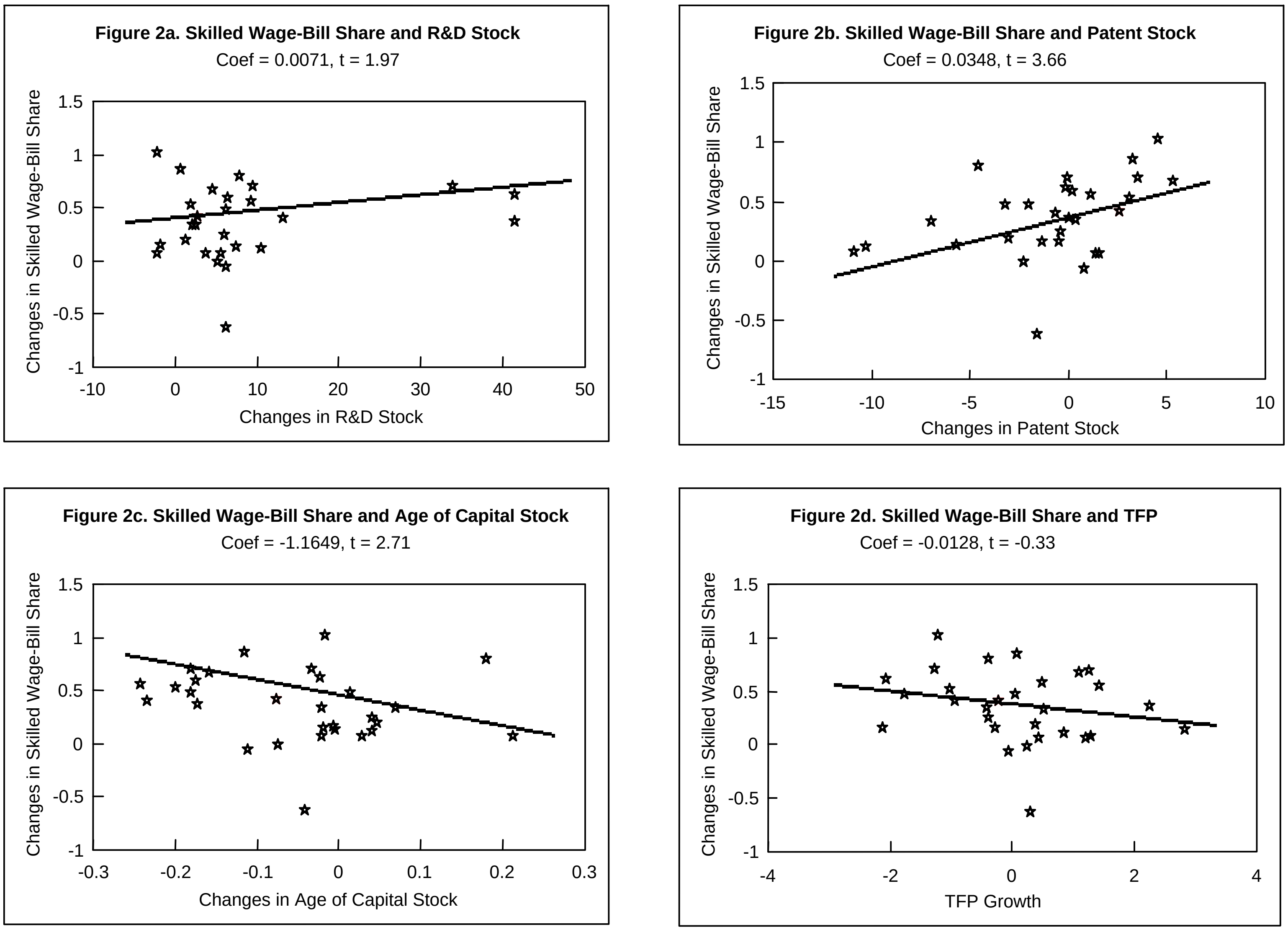

Table 10
Trends in the Wage-Bill Share of Skilled Workers and Measures of Technological Change

Industry	dS^1	dS^2	dln(K)	dln(Y)	dln(RD)	dln(P)	dA	dln(TFP)
Food and Beverage	0.26	0.42	2.80	0.37	2.76	2.59	-0.076	-0.23
Tobacco Products	-0.78	0.16	0.82	-5.14	-1.84	-0.53	-0.020	-0.28
Rubber and Plastics	0.81	0.86	4.21	3.48	0.63	3.26	-0.116	0.06
Leather	0.92	0.48	0.02	-3.95	6.10	-3.20	-0.181	0.05
Textiles	-1.18	-0.62	-0.30	-0.33	6.10	-1.58	-0.043	0.29
Clothing	0.07	-0.06	1.18	-0.19	6.10	0.79	-0.111	-0.06
Wood	-0.02	0.12	1.39	3.36	10.57	-10.32	0.039	0.83
Furniture and Fixtures	0.13	0.71	2.53	-0.18	9.34	3.50	-0.033	-1.27
Paper and Allied Products	0.91	0.53	5.17	0.26	1.86	3.06	-0.200	-1.03
Printing, Publishing & Allied	1.21	0.41	5.34	1.67	13.08	-0.68	-0.235	-0.96
Primary Metals	0.16	0.34	2.51	1.18	2.02	-7.00	-0.021	0.52
Metal Fabricating	-0.35	-0.01	1.06	0.53	5.05	-2.25	-0.074	0.24
Machinery Industries	1.12	0.35	2.26	-1.65	2.55	0.36	0.068	-0.43
Transportation Equipment	0.88	0.59	7.15	5.42	6.29	0.19	-0.176	0.47
Electrical Products	0.44	0.56	7.41	6.26	9.16	1.17	-0.243	1.41
Non-metallic Minerals	0.90	0.07	-0.77	0.34	3.77	1.35	0.028	0.44
Petroleum & Coal Products	-0.39	0.20	1.89	0.82	1.14	-3.07	0.047	0.37
Chemicals & Chem. Products	-0.44	0.07	2.93	3.61	5.45	1.55	0.213	1.19
Transportation	0.18	0.08	1.68	2.90	-2.28	-10.90	-0.022	1.29
Storage	1.83	1.03	3.06	-1.40	-2.28	4.56	-0.017	-1.22
Communication	-1.17	0.14	4.01	5.37	7.41	-5.68	-0.006	2.81
Electric Power, Gas & Water	0.03	0.80	4.41	1.85	7.73	-4.56	0.179	-0.41
Wholesale	0.95	0.70	2.85	5.11	33.79	-0.08	-0.182	1.25
Retail	1.34	0.68	2.37	2.73	4.59	5.34	-0.158	1.09
Finance	0.25	0.62	8.60	1.54	41.43	-0.17	-0.024	-2.08
Insurance	0.12	0.37	11.41	6.35	41.43	0.00	-0.173	2.25
Amusement & Recreation	1.02	0.48	7.97	3.51	---	-2.07	0.013	-1.77
Accomm. & Food Services	0.36	0.17	8.27	0.07	---	-1.39	-0.007	-2.12
Construction	-0.38	0.25	4.22	1.96	5.93	-0.39	0.040	-0.41

dS^1: Annual change in the wage-bill share of NOC skilled workers over the 1981–94 period (percentage points);
dS^2: Annual change in the wage-bill share of knowledge workers over the 1981–94 period (percentage points);
dln(K): Annual rate of change in the capital stock over the 1981–90 period (percent);
dln(Y): Annual rate of change in real output over the 1981–90 period (percent);
dln(RD): Annual rate of change in the R&D stock over the 1981–90 period (percent);
dln(P): Annual rate of change in the patent stock over the 1981–90 period percent);
dA: Annual change in the age of the capital stock over the1981–90 period years);
dln(TFP): Annual rate of change in total factor productivity over the 1981–90 period (percent).

Table 11
Wage-Bill and Employment Share Equations – NOC Skilled Workers*

(a) Dependent Variable: Wage-Bill Share of Skilled Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0332 (1.199)	-0.1093 (-2.896)	-0.0260 (-0.728)	0.0043 (0.161)	-0.0348 (-0.687)	-0.0732 (-1.202)
Log of Real Output	-0.0025 (-0.086)	0.0083 (0.228)	0.0134 (0.326)	-0.0257 (-0.914)	0.0056 (0.079)	-0.0870 (-1.171)
Log of R&D Stock		0.0119 (1.783)				0.0152 (2.335)
Log of Patent Stock			0.0429 (2.194)			0.0488 (2.631)
Age of Capital Stock				-0.0212 (-5.046)		-0.0145 (-2.042)
Log of TFP					-0.0276 (-0.220)	0.2286 (1.582)
Time Trend	0.0022 (1.573)	0.0054 (3.404)	0.0047 (2.496)	0.0021 (1.568)	0.0049 (2.755)	0.0047 (2.693)
Log of Relative Wages of Skilled Workers	0.0878 (3.430)	0.1740 (4.573)	0.0372 (1.404)	0.0518 (2.058)	0.0374 (1.406)	0.1997 (5.177)
R Squared	0.96	0.98	0.98	0.97	0.98	0.98
N**	232	162	168	232	174	156

(b) Dependent Variable: Employment Share of Skilled Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0111 (0.460)	-0.1025 (-2.817)	-0.0366 (-1.203)	-0.0083 (-0.355)	-0.0224 (-0.491)	-0.0391 (-0.667)
Log of Real Output	0.0201 (0.772)	0.0157 (0.447)	0.0308 (0.853)	-0.0001 (0.004)	-0.0160 (-0.250)	-0.0952 (-1.321)
Log of R&D Stock		0.0098 (1.513)				0.0144 (2.274)
Log of Patent Stock			0.0496 (2.949)			0.0528 (3.001)
Age of Capital Stock				-0.0169 (-4.810)		-0.0097 (-1.401)
Log of TFP					0.0521 (0.459)	0.2775 (1.975)
Time Trend	0.0023 (1.856)	0.0054 (3.597)	0.0046 (2.836)	0.0019 (1.596)	0.0048 (3.020)	0.0039 (2.358)
Log of Relative Wages of Skilled Workers	-0.0586 (-2.888)	-0.0193 (-0.541)	-0.0876 (-4.179)	-0.0870 (-4.317)	-0.0844 (-3.939)	0.0146 (0.409)
R Squared	0.97	0.98	0.98	0.97	0.98	0.98
N**	232	162	168	232	174	156

* All regressions are OLS weighted by average wage-bill and employment shares respectively in two consecutive years for each industry. All specifications include a full set of industry dummies; t-statistics are in parentheses.

** Time periods vary across specifications: (1) and (2) cover the 1981–94 period, and (3) to (6) cover the 1981–90 period. Specifications (2) and (6) exclude two industries: amusement & recreation, and accommodations & food services, due to a lack of data on the R&D capital stock.

Table 12
Wage-Bill and Employment Share Equations – Knowledge Workers*

(a) Dependent Variable: Wage-Bill Share of Knowledge Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0140 (0.901)	-0.0375 (-1.572)	0.0018 (0.089)	0.0109 (0.691)	0.0053 (0.184)	0.0007 (0.019)
Log of Real Output	0.0235 (1.430)	0.0637 (2.763)	0.0634 (2.754)	0.0202 (1.210)	0.0483 (1.202)	-0.0175 (-0.364)
Log of R&D Stock		0.0077 (1.789)				0.0101 (2.349)
Log of Patent Stock			0.0259 (2.327)			0.0176 (1.367)
Age of Capital Stock				-0.0025 (-1.017)		-0.0116 (-2.448)
Log of TFP					0.0238 (0.331)	0.1590 (1.700)
Time Trend	0.0025 (3.247)	0.0012 (1.125)	0.0009 (0.819)	0.0025 (3.197)	0.0008 (0.740)	0.0005 (0.435)
Log of Relative Wages of Skilled Workers	0.0157 (1.300)	0.0035 (0.168)	-0.0114 (-0.884)	0.0135 (1.095)	-0.0133 (-1.016)	0.0083 (0.378)
R Squared	0.92	0.94	0.94	0.92	0.94	0.94
N**	232	162	168	232	174	156

(b) Dependent Variable: Employment Share of Knowledge Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0063 (0.517)	-0.0235 (-1.207)	0.0008 (0.055)	0.0058 (0.465)	0.0214 (0.914)	0.0251 (0.775)
Log of Real Output	0.0323 (2.462)	0.0501 (2.664)	0.0596 (3.226)	0.0314 (2.348)	0.0249 (0.760)	-0.0320 (-0.803)
Log of R&D Stock		0.0072 (2.072)				0.0099 (2.802)
Log of Patent Stock			0.0264 (3.009)			0.0162 (1.532)
Age of Capital Stock				-0.0006 (-0.312)		-0.0065 (-1.657)
Log of TFP					0.0700 (1.190)	0.1761 (2.251)
Time Trend	0.0020 (3.233)	0.0009 (1.100)	0.0010 (1.204)	0.0020 (3.178)	0.0007 (0.886)	0.0001 (0.082)
Log of Relative Wages of Skilled Workers	-0.0398 (-4.595)	-0.0724 (-4.403)	-0.0513 (-5.573)	-0.0403 (-4.556)	-0.0520 (-5.538)	-0.0608 (-3.441)
R Squared	0.92	0.94	0.94	0.92	0.94	0.94
N**	232	162	168	232	174	156

* All regressions are OLS weighted by average wage-bill and employment shares respectively in two consecutive years for each industry. All specifications include a full set of industry dummies; t-statistics are in parentheses.

** Time periods vary across specifications: (1) and (2) cover the 1981–94 period, and (3) to (6) cover the 1981–90 period. Specifications (2) and (6) exclude two industries: amusement & recreation, and accommodations & food services, due to a lack of data on the R&D capital stock.

CONCLUSIONS

There have been very few previous studies focusing on the major causes of skill upgrading in Canadian industries. Potentially the most important issue is whether biased technological change has been the major cause of skill upgrading in Canadian industries. In this paper, we examined two questions: First, has skill intensity risen across Canadian industries over the 1981–94 period? Second, is biased technological change the main cause for the shift in demand toward skilled workers?

To address these issues, we used broader occupational distinctions to develop two alternative industry-based skill measures — one based on the skill classification identified in the National Occupational Classification (NOC), and the other based on the skill classification scheme proposed by Wolff and Baumol (1989). Next, we combined data on skills with four industry-level measures of technology: the stock of research and development (R&D), the stock of patents used by industry, total factor productivity, and the age of the capital stock.

Our major findings are as follows:

First, an analysis of the time series of aggregate changes in relative employment and wage-bill share, relative labour supply, and relative wages of skilled workers between 1981 and 1994 suggests that the relative demand for more-skilled workers increased during the period. We find that the rise in skill intensity is pervasive across industries. Underlying the overall upskilling trend, we find some evidence of higher skill upgrading in service industries during the 1981–94 period.

Second, the shift in demand toward more-skilled workers since the beginning of the 1980s is entirely driven by “within-industry” skill utilization rather than “between-industry” employment shifts. This is true both in manufacturing and in services. As argued by Berman, Bound and Griliches (1994), this evidence seems consistent with the view that biased technological change has played a dominant role in skill upgrading. In their view, the bulk of skill upgrading that occurred in U.S. manufacturing industries can not be attributed to trade. Trade should induce employment shifts toward relatively high-skill industries, and away from low-skill ones, rather than overall upskilling within each industry.

Third, technology indicators — R&D capital, the stock of patents used by industry, the age of the capital stock – are generally found to be strongly correlated with skill intensity. From this we infer that biased technological change has been a key factor to within-industry skill upgrading across Canadian industries. On the basis of our results, we calculate that the R&D capital stock explains as much as 34 to 44 percent of the increase in the wage-bill share of more-skilled workers since the beginning of the 1980s. The age of the capital stock accounts for 50 to 60 percent of the total shift in the demand for skilled workers over the 1981–90 period. The stock of patents is not a contributing factor to the overall skill upgrading over that period. Regardless of the causal relationships, our results imply that skill upgrading has occurred both in industries that invested heavily in new capital during the 1980s and in those that are R&D capital-intensive.

Fourth, our estimates do not provide support for general capital-skill complementarity in Canadian data. However, on the basis of the evidence of strong correlation between the age of the capital stock and skill intensity, our results do imply complementarity of younger capital stock and skills.

In conclusion, we would like to make a few observations. First, we find that biased technological change explains almost all the shift in the demand for skilled labour observed across Canadian industries over the 1981–90 period. These results imply that trade may not have played a significant role in skill upgrading across Canadian industries. We suggest that this issue needs to be addressed in an appropriate framework in which technology, trade and foreign direct investment interact together. Moreover, measures of technological change such as computer usage, computer capital per worker, and computer investment as a share of total investment should be included in the empirical analysis. As argued by Autor, Katz and Krueger (1997), the study needs to take a longer-term perspective than the last fifteen years or even a comparison of the 1980s with the 1970s.

Second, our results point in particular to the role that R&D capital plays in skill upgrading. These findings reinforce the importance of the interaction between human capital accumulation and innovation efforts in the knowledge-based economy. Recent literature in this area claims that the key source of lasting competitive advantage in the knowledge-based economy is the creation and generation of knowledge, technology, and human capital (see, for example, Gera, Lee-Sing and Newton, 1998).

Finally, an interesting question is: If skill intensity has been rising across Canadian industries since the beginning of the 1980s, why has productivity growth been so slow? Our research offers no direct answer to this question. However, our findings of somewhat higher skill upgrading in services combined with slower TFP growth rates over the 1980s provides indirect evidence of the familiar problem of output mismeasurement in services.

NOTES

1 In most studies, skill-biased technical change is inferred rather than observed directly, with the exception of Levy and Murnane (1996) who provide direct evidence on the impact of computers on skill demand.

2 However, recent studies (see, for example, DiNardo and Pischke, 1996) cast some doubt on the interpretation of the computer-use wage differentials as reflecting productivity effects arising from the introduction of computers in the workplace.

3 Using U.S. data from the 1988 Survey of Manufacturing Technology and the 1987 Census of Manufacturers, Dunne and Schmitz (1995) find that establishments using computer-based technologies pay higher wages than other establishments.

4 An important aspect that is missing from work such as Baldwin et al (1997) is the ability to control for human capital of workers. Hence, one does not know if the companies using advanced technologies pay higher wages because of the productivity enhancing effect of the technology, or simply because they employ higher skilled labour.

5 McMullen (1996) notes that the Working With Technology Survey III results suggest quite strongly that the occupational and skills structure appears to be moving definitely towards employment of highly skilled professional, technical, and managerial workers and away from employment of unskilled workers.

6 Professional occupations (skill level A) generally require a university degree, technical occupations (skill level B) require two to three years of post-secondary education at a community college, intermediate occupations (skill level C) require one to four years of secondary school education, and unskilled occupations (skill level D) require up to two years of secondary school education. For details on the NOC skill level criteria, see *National Occupational Classification: Occupational Descriptions*, Minister of Supply and Services Canada, 1993.

7 According to Wolff and Baumol (1989), an occupation can be classified into one of six categories: knowledge production, data processing, supply of services, goods production, a hybrid class including both knowledge and data activities, and a hybrid class including both data and service activities (the details are provided in Table 2A of the Appendix). The hybrid knowledge/data category is then split half into knowledge workers and half into data workers. In a similar fashion, the hybrid data/service category is split half into data workers and half into service workers. The resulting four skill groups are referred to as the " knowledge", "data", "goods" and "services" workers.

8 Berman, Bound and Griliches (1994) argue that as long as the elasticity of substitution between skilled and unskilled labour is above one, changes in the wage bill share of skilled workers provides a better measure of the demand shift toward skilled labour. The underlying assumption is that the increase in relative wages of skilled workers, if it happens, would induce substitution away from skilled labour.

9 Berman, Bound and Griliches (1994) argue that the rise in skill intensity in U.S. manufacturing industries cannot be accounted for by overseas production of labour-intensive activities. To these authors, the fact that the rise in the ratio of nonproduction to production workers is as pervasive at

the four-digit level as it is at the two-digit level suggests that the rise in skill intensity does not reflect outsourcing.

10 Berman, Bound and Griliches (1994) argue that there may be other forces at work that could shift the composition of the demand for labour toward relatively skilled workers. For example, foreign outsourcing of unskilled-intensive activities could also generate within-industry increases in the relative employment of more-skilled workers.

11 Baldwin (1995) criticised this interpretation, however, since trade and technological change both produce substitution and income effects, affecting the employment of workers in industry as well as its skill mix.

12 Berman, Bound and Griliches (1994) reach a similar conclusion in that the within-industry component dominates the between-industry component for the growth of the nonproduction worker employment and wage bill shares in manufacturing.

13 Berndt, Morrison and Rosenblum (1992) suggest that the time trend T may also reflect a gradual increase over time in the relative supply of skilled workers due to demographic shifts.

14 The stock of R&D is calculated using data on R&D expenditures from Statistics Canada. Using a perpetual inventory method with a depreciation rate of .15, the stock of patents is calculated from the number of patents granted that were used, by industry and by application year. The Canadian Intellectual Property Office (CIPO) provided the data on patent counts. Total factor productivity and the age of capital stock are aggregated from Statistics Canada's KLEMS and capital stock data.

15 The fixed effect estimation model used will control for any persistent variation across industries in the likelihood of patenting an innovation.

16 A strong evidence in support of the embodiment hypothesis was found for the G7 countries at the aggregate level by Wolff (1996*b*), while Gera, Gu and Lee (1999) found strong and robust evidence of embodied technical progress among Canadian industries.

17 Griliches and Hauseman (1986) made this point as well. Allen (1996) also argued that using such an approach could lead to unreasonable results due to a measurement error.

18 Data on the age of the capital stock, real value added, and capital stock are available until 1994. Hence, a few of our regression specifications include data for the period 1981–94. Two industries, namely miscellaneous manufacturing and miscellaneous services, are excluded from the sample due to data problems.

19 The fitted line shown in the graphs is based upon the weighted least square estimates. The weights represent the average wage bill share of each industry.

20 Similar raw correlations exist between increases in the share of skilled workers in employment and the various proxies for technological change.

21 Other studies have also reported similar findings (see, for example, Lawrence and Slaughter, 1993). Bartel and Sicherman (1997) find that input-based measures of technological change, as opposed to output-based measures, show a strong relationship with wages.

22 Wolff (1997) suggests that TFP in services seems to suffer much more than in manufacturing industries due to the major restructuring associated with new technology. This might reflect much higher adjustment costs to new technology. The negative TFP growth in services may also be due to a measurement error for service output.

23 Bartel and Lichtenberg (1987) find that the effect of the age of the capital stock on the wage bill share of skilled workers depends upon the R&D intensity of the industry.

BIBLIOGRAPHY

Allen, Steven G., "Technology and the Wage Structure." NBER Working Paper No. 5534, 1996.

Autor, David H., Lawrence F. Katz and Alan B. Krueger, "Computing Inequality: Have Computers Changed the Labour Market?" NBER Working Paper No. 5956, 1997.

Baily, Martin N. and Robert J. Gordon, "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Powers." *Brookings Papers on Economic Activity*, 2(1988): 347-420.

Baldwin, John R., T. Gray, and J. Johnson, "Technology-induced Wage Premia in the Canadian Manufacturing Plants during the 1980s." Working Paper No. 92, Analytical Studies Branch, Statistics Canada, 1997.

Baldwin, John R. and Mohammed Rafiquzzaman, "Trade, Technology, and Wage Differentials in the Canadian Manufacturing Sector," *in Innovation, Industry Evolution, and Employment*, edited by David B. Audretsch and A. Roy Thurik, Cambridge University Press, 1998, forthcoming.

Baldwin, Robert E., "The Effects of Trade and Foreign Direct Investment on Employment and Wages." OECD Economic Studies No. 23, Winter 1995.

Bartel, Ann P. and Frank R. Lichtenberg, "The Comparative Advantage of Educated Workers in Implementing New Technology." *Review of Economics and Statistics*, 69(1987): 1-11.

Bartel, Ann P. and Frank R. Lichtenberg, "The Age of Technology and its Impact on Employee Wages." *Economic Innovation and New Technology*, 1(2) (1991): 215-31.

Bartel, Ann P. and Nachum Sicherman, "Technological Change and Wages: An Inter-Industry Analysis." NBER Working Paper No. 5941, 1997.

Berman, Eli, John Bound and Zvi Griliches, "Changes in the Demand for Skilled Labour within U.S. Manufacturing Industries: Evidence from Annual Survey of Manufacturing." *Quarterly Journal of Economics*, 109 (1994): 367–98.

Berman, Eli, John Bound and Stephen Machin, "Implications of Skill-Biased Technological Change: International Evidence." NBER Working Paper No. 6166, 1997.

Berndt, Ernst R., Catherine, J. Morrison and Larry S. Rosenblum, "High-Tech Capital Formation and Labour Composition in U.S. Manufacturing Industries: An Exploratory Analysis." NBER Working Paper No. 4010, 1992.

Blackburn, Mckinley, David Bloom, and Richard Freeman, "The Declining Economic Position of Less Skilled American Males," in *A Future of Lousy Jobs*? Edited by Gary Burtless, Washington, D.C.: Brookings Institution, 1990.

Borjas, George J., "Economic Benefits from Immigration." *Journal of Economic Perspectives*, 9(2) (1995): 3-22

Borjas, George J., Richard B. Freeman and Lawrence F. Katz, "On the Labour Effects of Immigration and Trade," in *Immigration and the Workforce: Economic Consequences for the United States and Source Area*, edited by George J. Borjas and Richard B. Freeman, University of Chicago, 1992.

Borjas, George J. and Valerie A. Ramey, "Foreign Competition, Market Power, and Wage Inequality." *Quarterly Journal of Economics*, 110(4) (1995): 1075-110.

Bound, John and George Johnson, "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations." *American Economic Review*, 82(1992): 371–92.

Burbidge, J. B., L. Magee and A. L. Robb, "Canadian Wage Inequality over the Last Two Decades." Unpublished Paper, McMaster University, Canada, 1996.

DiNardo, John, Nicole Fortin and Thomas Lemieux, "Labour Market Institutions and the Distribution of Wages, 1973-1992: A Semi-Parametric Approach." *Econometrica* 64 (September 1996): 1001-44.

DiNardo, John and Jorn-Steffen Pischke, "The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too?", NBER Working Paper No. 5606, 1996.

Doms, Mark, Timothy Dunne and Kenneth R. Troske, "Workers, Wages, and Technology." *Quarterly Journal of Economics*, (February 1997): 253–90.

Dunne, T. and J.A. Schmitz Jr, "Wages, Employment Structure and Employer Size-Wage Premia: Their Relationship to Advanced Technology Usage at U.S. Manufacturing Establishments." *Economica*, 62(1995): 88-107.

Freeman, Richard B., "Labour Market Institutions and Earnings Inequality." *New England Economic Review*, (May/June 1996): 157-68.

Freeman, R. B. and K. Needels, "Skill Differentials in Canada in an Era of Rising Labor Market Inequality." In *Small Differences that Matter*, edited by R.B. Freeman and D. Card, University of Chicago Press for the NBER, 1991.

Gera, Surendra, Wulong Gu and Frank C. Lee, "Capital-Embodied Technical Change and the Productivity Slowdown in Canada." Industry Canada Working Paper No. 21, 1998.

Gera, Surendra, Clifton Lee-Sing and Keith Newton, "Global Trends and the Knowledge-Based Economy," Unpublished Paper, Industry Canada, 1998.

Griliches, Zvi and Jerry A. Hauseman, "Errors in Variables in Panel Data." *Journal of Econometrics*, 31(1986): 93-118.

Katz, Lawrence and Kevin Murphy, "Changes in Relative Wages, 1963-1987: Supply and Demand Factors." *Quarterly Journal of Economics*, CVII (1992): 35-78.

Kruger, Alan B. "How Computers Have Changed the Wage Structure? Evidence from Micro Data." *Quarterly Journal of Economics*, (February 1993): 33-60.

Kuhn, Peter, "Labour Market Polarization: Canada in International Perspective." Unpublished Paper, Department of Economics, McMaster University, 1995.

Lavoie, Marie and Richard Roy, "Employment in the Information Economy: A Growth Accounting Exercise for Canada." Human Resources Development Canada, memo, 1998.

Lawrence, Robert Z. and Matthew J. Slaughter, "International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hiccup?" Brookings Paper on Economic Activity, *Microeconomics* 2(1993): 161-226.

Leamer, Edward, "In Search of Stoper-Samuelson Effects on U.S. Wages," in *Imports, Exports, and the American Worker*, edited by Susan Collins, The Brookings Institution, Washington, D.C., 1995.

Levy, Frank and Richard J. Murnane, "With What Skills are Computers a Complement?" *American Economic Review*, 86(May 1996): 258-62.

Lee, Frank C., "Implications of Technology and Imports on Employment and Wages in Canada." Industry Canada Working Paper No. 12, 1996.

Machin, Stephen, Annette Ryan and John Van Reenen, "Technology and Changes in Skill Structure: Evidence from an International Panel of Industries." Centre for Economic Performance Discussion paper No. 297, London School of Economics and Political Science, London, England, 1996.

McMullen, Kathryn, "Skill and Employment Effects of Computer-Based Technology." CPRN Study No. W01, Canadian Policy Research Networks Inc., Ottawa, 1996.

Morissette RenJ and Marie Drolet, "Computers, Fax Machines and Wages in Canada: What Really Matters?" Unpublished Paper, Business and Labour Market Analysis Division, Statistics Canada, 1997.

Murphy, Kevin, Craig Riddell and Paul Romer, "Wages and Technology in the United States and Canada." The Canadian Institute for Advanced Research, 1997.

Murphy, Kevin and Finis Welch, "The Structure of Wages." *Quarterly Journal of Economics*, CVII (1992): 258-326.

Sachs, Jeffrey D. and Howard J. Shatz, "Trade and Jobs in U.S. Manufacturing." Brookings Paper on Economic Activity, 1(1994): 1-84.

Siegel, S. Donald, "The Impact of Technological Change on Employment: Evidence from a Firm-Level Survey of Long Island Manufacturers." *Economics of Innovation and New Technology*, 5 (2-4) (1998): 227-46.

Wolff, N. Edward, "Indirect Measures of Productivity Growth in the Service Sector." Paper presented to the CSLS Conference on Service Sector Productivity and the Productivity Paradox, Ottawa, Canada, 1997.

Wolff, N. Edward, "The Growth of Information Workers in the U.S. Economy, 1950-1990: The Role of Technological Change, Computerization, and Structural Change." Department of Economics, New York University, Working Paper, 1996*a*.

Wolff, N. Edward, "The Productivity Slowdown: The Culprit at Last?" *American Economic Review*, 86(1996*b*): 1239-52.

Wolff, N. Edward and William J. Baumol, "Sources of Postwar Growth of Information Activity in the United States." In *The Information Economy: The Implications of Unbalanced Growth*, Lars Osberg, Edward N. Wolff and William J. Baumol (eds.), Institute for Research on Public Policy, 1989.

Wood, Adrian, *North-South Trade, Employment and Inequality*, Oxford: Clarendon Press, 1994.

APPENDIX

Table A1
NOC Skill Classification of Occupations

No.	Occupation Name	1980 SOC Code	Classification
1	Officials & Administrators, Gov't	111	Managers
2	Other Managers & Administrators	113-114	Managers
3	Management & Administration Related	117	Professional
4	Physical and Life Sciences	211-213	Professional
5	Maths, Stats, Systems Analysis and Related	218	Professional
6	Architects and Engineers	214-215	Professional
7	Architecture & Engineering Related	216	Technical Skilled
8	Social Sciences and Related	231, 233-235, 239	Professional
9	Religion	251	Technical Skilled
10	University and Related	271	Professional
11	Elementary, Secondary and Related	273	Professional
12	Other Teaching and Related	279	Professional
13	Health Diagnosing and Treating	311	Professional
14	Nursing, Therapy and Related	313	Professional
15	Medicine and Health Related	315-316	Technical Skilled
16	Artistic and Recreational	331, 333, 335-337	Technical Skilled
17	Stenographic and Typing	411	Technical Skilled
18	Bookkeeping, Account-Recording and Related	413	Interm. & Unskilled
19	Office Machine and EDP Operators	414	Interm. & Unskilled
20	Material Recording, Scheduling, & Distributing	415	Interm. & Unskilled
21	Reception, Info. Mail and Message Distribution	417	Interm. & Unskilled
22	Library, File, Corres., Other Clerical & Related	416, 419	Interm. & Unskilled
23	Sales, Commodities	513-514	Interm. & Unskilled
24	Sales, Services and Other Sales	517, 519	Technical Skilled
25	Protective Services	611	Interm. & Unskilled
26	Food & Bev. Preparation; Lodging and Accom.	612-613	Interm. & Unskilled
27	Personal, Apparel & Furnishing Services	614, 616	Interm. & Unskilled
28	Other Service Occupations	619	Interm. & Unskilled
29	Farmers and Farm Management	711, 713	Technical Skilled
30	Other Farming, Horticultural & Animal Husbandry	718-719	Interm. & Unskilled
31	Fishing, Hunting, Trapping and Related	731	Interm. & Unskilled
32	Forestry and Logging	751	Interm. & Unskilled
33	Mining & Quarrying Including Gas & Oil Fields	771	Interm. & Unskilled
34	Food, Beverage and Related	821-822	Interm. & Unskilled
35	Other Processing Occupations	823, 825-827, 829, 813-817, 811	Interm. & Unskilled
36	Metal Shaping & Forming Occupations	833	Interm. & Unskilled
37	Other Machining Occupations	839, 835, 837, 831	Interm. & Unskilled
38	Metal Products, n.e.c.	851-852	Interm. & Unskilled
39	Electrical, Electronic and Related Equipment	853	Technical Skilled
40	Textiles, Furs & Leather Goods	855-856	Interm. & Unskilled
41	Wood Products, Rubber, Plastics & Related	854, 857, 859	Interm. & Unskilled
42	Mechanics & Repairmen, except Electrical	858	Technical Skilled
43	Excavation, Grading, Paving and Related	871	Interm. & Unskilled
44	Electrical Power, Lighting & Wire Comm.	873	Technical Skilled
45	Other Construction Trades	878-879	Technical Skilled
46	Motor Transport Operators	917	Interm. & Unskilled
47	Other Transport Equipment Operators	911, 913, 915, 919	Interm. & Unskilled
48	Material Handling	931	Interm. & Unskilled

Table A2
Wolff & Baumol Skill Classification of Occupations

No.	Occupation Name	1980 SOC Code	Classification
1	Officials & Administrators, Gov't	111	Knowledge/Data
2	Other Managers & Administrators	113-114	Knowledge/Data
3	Management & Administration Related	117	Knowledge/Data
4	Physical and Life Sciences	211-213	Knowledge
5	Maths, Stats, Systems Analysis and Related	218	Knowledge
6	Architects and Engineers	214-215	Knowledge
7	Architecture & Engineering Related	216	Knowledge
8	Social Sciences and Related	231, 233-235, 239	Knowledge/Data
9	Religion	251	Data/Services
10	University and Related	271	Knowledge
11	Elementary, Secondary and Related	273	Data
12	Other Teaching and Related	279	Data
13	Health Diagnosing and Treating	311	Data/Services
14	Nursing, Therapy and Related	313	Data/Services
15	Medicine and Health Related	315-316	Data/Services
16	Artistic and Recreational	331, 333, 335-337	Knowledge/Data
17	Stenographic and Typing	411	Data
18	Bookkeeping, Account-Recording and Related	413	Data
19	Office Machine and EDP Operators	414	Data
20	Material Recording, Scheduling, & Distributing	415	Data
21	Reception, Info. Mail and Message Distribution	417	Data
22	Library, File, Corres., Other Clerical & Related	416, 419	Data
23	Sales, Commodities	513-514	Data
24	Sales, Services and Other Sales	517, 519	Data
25	Protective Services	611	Services
26	Food & Bev. Preparation; Lodging and Accom.	612-613	Services
27	Personal, Apparel & Furnishing Services	614, 616	Services
28	Other Service Occupations	619	Services
29	Farmers and Farm Management	711, 713	Goods
30	Other Farming, Horticultural & Animal Husbandry	718-719	Goods
31	Fishing, Hunting, Trapping and Related	731	Goods
32	Forestry and Logging	751	Goods
33	Mining & Quarrying Including Gas & Oil Fields	771	Goods
34	Food, Beverage and Related	821-822	Goods
35	Other Processing Occupations	823, 825-827, 829, 813-817, 811	Goods
36	Metal Shaping & Forming Occupations	833	Goods
37	Other Machining Occupations	839, 835, 837, 831	Goods
38	Metal Products, n.e.c.	851-852	Goods
39	Electrical, Electronic and Related Equipment	853	Goods
40	Textiles, Furs & Leather Goods	855-856	Goods
41	Wood Products, Rubber, Plastics & Related	854, 857, 859	Goods
42	Mechanics & Repairmen, except Electrical	858	Goods
43	Excavation, Grading, Paving and Related	871	Goods
44	Electrical Power, Lighting & Wire Comm.	873	Goods
45	Other Construction Trades	878-879	Goods
46	Motor Transport Operators	917	Goods
47	Other Transport Equipment Operators	911, 913, 915, 919	Goods
48	Material Handling	931	Goods

Table A3
Contributions to "Between–Industry" and "Within–Industry" Components of Changes in the Wage Bill Share of NOC Skilled Workers, 1981–94

Industry	Rank	Contribution	Within (percentage points)	Between
Other Services	1	2.45	0.78	1.67
Retail	2	1.73	2.21	-0.48
Electric Power, Gas & Water	3	1.42	0.01	1.41
Communication	4	1.39	-0.58	1.97
Transportation Equipment	5	1.24	0.52	0.71
Wholesale	6	0.97	0.93	0.04
Printing, Publishing & Allied	7	0.49	0.36	0.14
Transportation	8	0.48	0.15	0.33
Paper and Allied Products	9	0.46	0.39	0.07
Finance	10	0.38	0.23	0.15
Amusement & Recreation	11	0.25	0.16	0.09
Accommodation & Food Services	12	0.13	0.20	-0.07
Non-metallic Minerals	13	0.08	0.11	-0.03
Miscellaneous Manufacturing	14	0.07	0.10	-0.03
Storage	15	0.03	0.05	-0.02
Leather	16	0.01	0.03	-0.02
Insurance	17	0.01	0.03	-0.02
Rubber and Plastics	18	0.01	0.13	-0.11
Tobacco Products	19	-0.02	-0.01	-0.00
Wood	20	-0.07	-0.00	-0.07
Clothing	21	-0.08	0.01	-0.09
Furniture and Fixtures	22	-0.12	0.01	-0.14
Food and Beverage	23	-0.16	0.12	-0.28
Electrical Products	24	-0.18	0.15	-0.33
Textiles	25	-0.19	-0.12	-0.08
Petroleum & Coal Products	26	-0.20	-0.03	-0.17
Primary Metals	27	-0.23	0.06	-0.29
Metal Fabricating	28	-0.27	-0.11	-0.16
Chemicals & Chemical Products	29	-0.30	-0.11	-0.20
Machinery Industries	30	-0.46	0.24	-0.70
Construction	31	-2.49	-0.44	-2.05

Table A4
Contributions to "Between–Industry" and "Within–Industry" Components of Changes in the Wage Bill Share of Knowledge Workers, 1981–94

Industry	Rank	Contribution	Within (percentage points)	Between
Other Services	1	1.25	0.37	0.88
Retail	2	1.00	1.11	-0.11
Communication	3	0.81	0.07	0.74
Wholesale	4	0.71	0.69	0.02
Transportation Equipment	5	0.64	0.35	0.29
Electric Power, Gas & Water	6	0.62	0.17	0.45
Finance	7	0.62	0.56	0.06
Paper and Allied Products	8	0.25	0.23	0.03
Printing, Publishing & Allied	9	0.18	0.12	0.05
Transportation	10	0.17	0.07	0.10
Amusement & Recreation	11	0.11	0.07	0.04
Insurance	12	0.10	0.10	-0.01
Food and Beverage	13	0.09	0.20	-0.11
Construction	14	0.08	0.29	-0.20
Rubber and Plastics	15	0.07	0.13	-0.06
Electrical Products	16	0.07	0.19	-0.12
Accommodation & Food Services	17	0.06	0.09	-0.03
Miscellaneous Manufacturing	18	0.05	0.06	-0.01
Storage	19	0.02	0.03	-0.01
Wood	20	0.02	0.03	-0.02
Primary Metals	21	0.01	0.12	-0.11
Leather	22	0.01	0.02	-0.01
Tobacco Products	23	0.00	0.00	-0.00
Furniture and Fixtures	24	0.00	0.07	-0.07
Non-metallic Minerals	25	-0.00	0.01	-0.01
Clothing	26	-0.04	-0.01	-0.04
Metal Fabricating	27	-0.08	-0.00	-0.08
Textiles	28	-0.09	-0.06	-0.03
Chemicals & Chemical Products	29	-0.10	0.02	-0.12
Petroleum & Coal Products	30	-0.11	0.01	-0.12
Machinery Industries	31	-0.25	0.08	-0.33

Table A5
Correlation Matrix of the Different Measures of Technology*

	Log of R&D Stock	Log of Patent Stock	Age of Capital Stock	Log of TFP
Log of R&D Stock	1.000			
Log of Patent Stock	0.094	1.000		
Age of Capital Stock	0.017	-0.331	1.000	
Log of TFP	-0.068	0.317	0.151	1.000

* Correlation matrix based on a panel of 29 industries over the years 1981 and 1986 through 1990.

Table A6
Wage Bill and Employment Share Equations — NOC Skilled Workers*

(a) Dependent Variable: Wage Bill Share of Skilled Workers

Independent Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Log of Capital Stock	0.0167 (0.596)	-0.1328 (-3.342)	-0.0417 (-1.223)	-0.0080 (-0.304)	-0.0564 (-1.166)	-0.1494 (-2.299)
Log of Real Output	0.0079 (0.261)	0.0371 (0.966)	0.0305 (0.774)	-0.0228 (-0.803)	0.0334 (0.487)	-0.0074 (-0.093)
Log of R&D Stock		0.0135 (1.885)				0.0157 (2.175)
Log of Patent Stock			0.0439 (2.242)			0.0288 (1.446)
Age of Capital Stock				-0.0236 (-5.821)		-0.0238 (-3.150)
Log of TFP					-0.0490 (-0.392)	0.0727 (0.468)
Time Trend	0.0029 (1.999)	0.0052 (3.053)	0.0046 (2.459)	0.0024 (1.821)	0.0049 (2.723)	0.0051 (2.609)
R Squared	0.96	0.97	0.97	0.96	0.97	0.98
N**	232	162	168	232	174	156

(b) Dependent Variable: Employment Share of Skilled Workers

Independent Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Log of Capital Stock	0.0261 (1.084)	-0.0996 (-2.775)	0.0104 (0.347)	0.0171 (0.727)	0.0345 (0.758)	-0.0447 (-0.784)
Log of Real Output	0.0110 (0.418)	0.0125 (0.361)	-0.0193 (-0.534)	-0.0070 (-0.268)	-0.0861 (-1.334)	-0.895 (-1.270)
Log of R&D Stock		0.0096 (1.488)				0.0144 (2.289)
Log of Patent Stock			0.0457 (2.570)			0.0513 (2.991)
Age of Capital Stock				-0.0124 (-3.557)		-0.0104 (-1.547)
Log of TFP					0.0963 (0.812)	0.2667 (1.939)
Time Trend	0.0018 (1.424)	0.0054 (3.623)	0.0048 (2.783)	0.0013 (1.049)	0.0049 (2.971)	0.0040 (2.377)
R Squared	0.97	0.98	0.98	0.97	0.98	0.98
N**	232	162	168	232	174	156

* All regressions are OLS weighted by average wage bill and employment shares respectively in two consecutive years for each industry. All specifications include a full set of industry dummies; t-statistics are in parentheses.

** Time periods vary across specifications: (1) and (2) cover the 1981–94 period, while (3) to (6) cover the 1981–90 period. Specifications (2) and (6) exclude two industries: amusement & recreation, and accommodations & food services, due to a lack of data on R&D capital stock.

Table A7
Wage Bill and Employment Share Equations – Knowledge Workers*

(a) Dependent Variable: Wage Bill Share of Knowledge Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0107 (0.700)	-0.0377 (-1.589)	0.0068 (0.354)	0.0076 (0.493)	0.0125 (0.450)	-0.0008 (-0.021)
Log of Real Output	0.0232 (1.414)	0.0638 (2.784)	0.0585 (2.620)	0.0194 (1.162)	0.0402 (1.020)	-0.0165 (-0.345)
Log of R&D Stock		0.0077 (1.793)				0.0101 (2.351)
Log of Patent Stock			0.0266 (2.392)			0.0158 (1.327)
Age of Capital Stock				-0.0029 (-1.234)		-0.0121 (-2.678)
Log of TFP					0.0288 (0.401)	0.1551 (1.674)
Time Trend	0.0026 (3.336)	0.0011 (1.118)	0.0010 (0.954)	0.0025 (3.265)	0.0009 (0.888)	0.0004 (0.367)
R Squared	0.92	0.94	0.94	0.92	0.94	0.94
N**	232	162	168	232	174	156

(b) Dependent Variable: Employment Share of Knowledge Workers

Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of Capital Stock	0.0173 (1.375)	-0.0201 (-0.966)	0.0304 (1.864)	0.0181 (1.426)	0.0568 (2.288)	0.0386 (1.151)
Log of Real Output	0.0316 (2.296)	0.0481 (2.393)	0.0313 (1.597)	0.0331 (2.360)	-0.0147 (-0.419)	-0.0414 (-0.999)
Log of R&D Stock		0.0072 (1.932)				0.0101 (2.733)
Log of Patent Stock			0.0288 (2.977)			0.0307 (3.041)
Age of Capital Stock				0.0011 (0.573)		-0.0027 (-0.689)
Log of TFP					0.0930 (1.439)	0.2114 (2.614)
Time Trend	0.0018 (2.766)	0.0017 (1.958)	0.0017 (1.814)	0.0018 (2.809)	0.0014 (1.530)	0.0007 (0.748)
R Squared	0.91	0.93	0.93	0.91	0.93	0.94
N**	232	162	168	232	174	156

* All regressions are OLS weighted by average wage bill and employment shares respectively in two consecutive years for each industry. All specifications include a full set of industry dummies; t-statistics are in parentheses.

** Time periods vary across specifications: (1) and (2) cover the 1981–94 period, while (3) to (6) cover the 1981–90 period. Specifications (2) and (6) exclude two industries: amusement & recreation, and accommodations & food services, due to a lack of data on R&D capital stock.

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