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ABSTRACT

This study examines the significant role of computers in the transformation of the Canadian employment structure. An executive summary appears in English and French. Following an introduction, Section 2 discusses how the role of computerization of the employment structure is viewed in the literature. Section 3 presents an overview of past developments in computer technology leading up to the contemporary microcomputer. Section 4 describes important trends (capital intensity and computer intensity) in the evolution of the Canadian industrial structure over the last few decades and proposes an industrial taxonomy on which to base analysis. Section 5 examines how these intensity trends affect different categories of employment: management, knowledge, data, service, and goods workers. Section 6 develops a methodology inspired from the production function framework of Berman, Bound, and Griliches (1993) and explains the data used. The remainder of the paper presents empirical results in these three sections. Section 7 deals with relative wages. Section 8 analyzes the capital/skill complementarity. Section 9 discusses the association of computers with different categories of workers. Section 10 includes a summary of the main findings, outlines some broad implications, and indicates avenues for further research. Appendixes contain descriptive statistics by industry in 1971 and 1991, and a 51-item bibliography. (YLB)

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Employment Effects of Computerization, 1971-1991

W-99-2E

by
Marie Lavoie and Pierre Therrien
May 1999

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Abstract

A 1998 study by Marie Lavoie and Richard Roy entitled *Employment in the Knowledge-Based Economy: A Growth Accounting Exercise for Canada* discovered a rapid and widespread trend across industrial sectors toward employment favouring high-skilled workers. Given the simultaneity of this trend with the increasing diffusion of information and communication technologies – in which the computer is key, in the present study the authors examine the significant role of computers in the transformation of the employment structure. At the same time that this employment transformation occurred, industries inherited from the past were profoundly altered and new ones created.

Computerization (the diffusion of a combination of hardware and software) has accelerated in the last 25 years due to advances in electronic technologies, the advent of the microprocessor and the tremendous development of the software industry. The process of codification of knowledge has intensified and routine tasks have tended to disappear, changing the architecture of jobs and, therefore, the structure of employment. An increasing number of occupations have become associated with the computer, and these jobs require highly skilled workers.

Using a production function framework, the researchers find that on the whole computerization is not labour-saving but rather labour-using. Moreover, by transforming the structure of jobs, the computer has changed the skills requirements across industries: the knowledge, management and data category of workers is closely associated with the use of computers while for goods workers the relationship is a substitutive one due to expert systems software. The computer because of the highly tacit nature of the tasks does not affect the service category of workers. Despite these general changes in the structure of jobs, important inter-industrial differences prevail in the association of skill patterns with the computer. Although this transformation process is clearly well underway, the low-skilled remain the largest contingent of workers in the Canadian economy.

Finally, it is clear that, as Berman, Bound and Griliches (1993) have said, the role of the computer in the change in the structure of employment should not be exaggerated. The computer has certainly acted as a catalyst for this "revolution," given its pervasiveness and its capacity to merge with other technologies, but it is certainly not the only factor affecting the employment structure.

Résumé

Une étude effectuée en 1998 par Marie Lavoie et Richard Roy : *Employment in the Knowledge-Based Economy : A Growth Accounting Exercise for Canada* a mis en évidence une tendance croissante de l'embauche de travailleurs hautement spécialisés dans tous les secteurs industriels. Puisque cette tendance coïncide avec une augmentation de la diffusion des technologies de l'information et des communications (l'ordinateur en étant la principale composante), les auteurs de l'étude ont voulu mieux comprendre le rôle joué par les ordinateurs. En même temps que ce changement prenait place, la structure industrielle se transformait: les industries héritées du passé subissaient de profondes transformations alors que de nouvelles voyaient le jour.

L'informatisation (c'est-à-dire la diffusion combinée d'ordinateurs et de logiciels) s'est accélérée au cours des vingt-cinq dernières années en raison de l'évolution des technologies électroniques, de la venue des microprocesseurs et des progrès énormes réalisés par l'industrie du logiciel. Cette diffusion a intensifié le processus de codification de la connaissance faisant en quelque sorte disparaître les tâches routinières et, par conséquent, contribuant à transformer la structure de l'emploi. Un nombre de plus en plus élevé d'emplois sont désormais associés à l'utilisation d'un ordinateur et exigent de la part des travailleurs des compétences hautement qualifiées.

Utilisant une fonction de production comme cadre d'analyse, les auteurs en arrivent à la conclusion que le processus d'informatisation n'a pas contribué à réduire considérablement la demande de main-d'oeuvre mais aurait plutôt eu tendance à l'augmenter de façon générale. Qui plus est, en transformant la structure des emplois, l'ordinateur a modifié les exigences ayant trait aux compétences dans tous les secteurs industriels : les catégories d'emplois liés au savoir, à la gestion et à la manipulation des données sont étroitement associées à l'utilisation d'ordinateurs, tandis que les emplois liés à la production de biens ont été substitués suite au développement de logiciels de systèmes experts. Finalement, les travailleurs dans la categorie d'emplois des services ne sont pas touchés par l'informatisation en raison de la nature tacite de leurs tâches. Malgré ces changements dans la structure générale des emplois, d'importantes différences intersectorielles prévalent dans la relation emploi/utilisation de l'ordinateur. Bien que ces vingt-cinq dernières années ont vu se dessiner une tendance ferme vers les travailleurs hautement qualifiés, les travailleurs peu spécialisés forment toujours la plus grande partie de la main-d'œuvre canadienne.

Il ressort donc de cette étude que l'impact de l'ordinateur sur le changement de la structure de l'emploi ne peut être exagéré comme le soulignent d'ailleurs Berman, Bound et Griliches (1993) dans le cas des Etats-Unis. Étant donné son caractère envahissant et sa capacité de se fusionner aux autres technologies, l'ordinateur a sûrement joué un rôle de catalyseur dans cette révolution mais ne peut être considéré comme étant l'unique facteur.

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1. Introduction

The employment effects of technology, in general, and of computers, in particular, have been a topic of controversy.[1] Some criticize the intrinsic *labour-saving bias*, which leads to income inequality and marginalizes a large category of workers, especially the low-skilled, forcing them to join the increasing ranks of the unemployed. For those who share this pessimistic vision, the end result is structural unemployment, where displaced workers have considerable problems becoming reemployed since they may not have the skills needed to work in a context in which technology is key. By altering employment composition, technology requires workers to pursue lifelong learning and to expend considerable effort to keep abreast of all the changes in both their private and their work lives.

This hostile view of technological change is however counterbalanced by another, more positive school of thought which claims essentially that technological change is a necessary condition for economic growth and, therefore, better standards of living and better income distribution (Dosi, Pavitt, Soete: 1990, Freeman, Clark, Soete: 1982, Watanabe: 1986). Among other things, it improves life expectancy through the development of new medical tools improving the diagnosis and treatment of diseases, it provides for the production of cheaper commodities and it can reduce the human input needed for routine and boring jobs. In any event, technological change has both negative and positive aspects.

Observers have often assumed, albeit largely by default, that technological change is the main cause of the increasing wage inequality and of the shift from unskilled to skilled in the labour force. The difficulty in measuring technological change and its direct employment effects largely explains the lack of empirical evidence (Carter: 1996). In this paper, we intend to focus on the effect of computerization on the employment structure by looking at degrees of complementarity and substitution of the computer for different groups of workers. The reason for limiting our

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[1] This paper begins the second part of a broad research agenda addressing employment in the knowledge-based economy. The first step was aimed at diagnosing the scope of the employment shift towards high-skilled workers and identifying sources of employment growth and was published in the research paper series of the Applied Research Branch (Lavoie, Roy: 1998). The second part of the agenda deals with the role of technological change in the employment structure and will be subdivided into two papers: this one – the first – deals with the impact of computer technology and the second will look at the complementarity between employment in the manufacturing sector and advanced manufacturing technologies. The same groups of occupations drawn from Wolff and Baumol are used throughout, and more detail on the occupational taxonomy can be found in Lavoie and Roy (1998).

research to the computer, when there are also many other technologies, is that we assume that the scope of diffusion and the related reduction in costs as well as the pervasiveness of the applications make computer equipment (hardware and software) responsible, at least in part, for the huge transformation in employment patterns. However, the impact is often taken for granted and only the job-reducing aspect across industries and occupations is emphasized. The purpose of this paper is to go beyond this accepted wisdom and explain inter-industrial and inter-occupational differences in the employment structure, leaving aside the question of the impact on the wage structure.

Depending on the production process of an industrial sector and the nature of the occupation, the computer can induce strong employment-enhancing effects as well as significant employment destroying ones. Our main assumption is that computerization complements some categories of skills and replaces others, depending on the nature of the tasks – tacit vs. codified and core vs. complementary. Of course, it would be simplistic to relate an increase in the demand for knowledge workers exclusively to skill-biased computerization. Technological change cannot be limited to computer technologies and computers may have a minimal effect compared with other equipment that radically transforms the production processes of industries. Moreover, the computer technology/skill complementarity may also be supplemented by supply-side factors, organizational change, increasing intensity of international trade in certain industrial sectors and the speed of structural adjustment. Given the explosive rate of computing technological change, its impact is worth assessing.

The paper begins by discussing how the role of computerization in the employment structure is viewed in the literature, to set up the context and present three hypotheses for further investigation. The computing machine of the early 1970s differs tremendously from the microcomputer and the "transputer" used nowadays. An overview of past developments in computer technology leading up to the contemporary microcomputer will be presented in the third section. This will help to better understand the computer revolution and its employment effects. In the fourth section, we document some important trends in the evolution of the Canadian industrial structure over the last few decades and propose an industrial taxonomy on which our analysis will be based. We then develop a methodology inspired from the production function framework of Berman, Bound and Griliches (1993) and explain the data used in Section 5. The remainder of the paper focuses on the presentation of empirical results and is split into three sections: one dealing with relative wages, the second analyzing the capital/skill complementarity and the last one discussing the association of computers with different categories of workers. The final section includes a summary of the main findings, outlines some broad implications and indicates avenues for further research.

2. Employment Effects of Computerization: A Conceptual Framework

The social consequences of unemployment and displacement of employment are so great that we need to have a better understanding of the related role of technological change. We cannot stop technological change but we can certainly attempt to adapt more quickly and efficiently to it by being able to better project its impact on future occupations and provide decision-makers with an appropriate picture on which to base adequate policy implementation.

Over time there have been pessimistic and optimistic views of the employment effects of technological change. In fact, what we have seen is a spiral trend of job creation and destruction. We still do not really understand the dynamics underlying the changes in the employment structure. We do know, however, that the different kinds of knowledge embodied in different categories of workers in various industries respond differently to the impact of diverse technologies. In short, the codification capacity of the computer combined with the differentiated nature of knowledge – codified and tacit – seems therefore to be part of the explanation. Moreover, whether a computer is used for core or for complementary activities seems to matter in terms of its employment effects. This quotation from Baldwin *et al* illustrates well the fact that not all human activities can be performed by the computer yet: "The introduction of labour-enhancing technologies has been stimulated by the recognition that humans possess the invaluable kind of dexterity and judgement that has yet to be programmed into a robot" (Baldwin, Gray, Johnson: 1997).

Our study[2] follows the 'skill-biased' tradition using a production function formulation where technological change (computerization) is described in terms of its biases, which are typically defined as labour-saving, capital-saving and neutral. However, instead of using this bias label,

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[2] While the potential of computer applications is endless, in this paper, the data on computer investment refer exclusively to final demand of input-output data in commodity 346 between 1971-1986 and commodity 359 between 1986-1991, that is, computers (hardware and software including "marketed software products" but excluding "custom designed software") and peripheral equipment. The data exclude all other computerized equipment, that is, equipment which combines electronic and mechanical technology as well as electronic and optics technology, and so on, or what have been called mechatronics and optoelectronics (Kodama:1991). This is very important to keep it in mind in the analysis since in the manufacturing sector, for example, advanced manufacturing technologies – which are a good example of technology fusion – are probably as important as the computer *per se*. Consequently, it is worth considering computer investment as a partial measure of technological change, although, as it also merges with equipment investment, it is more than likely that we also capture some general technological trends.

we instead talk in terms of complementary, substitutive or neutral associations between categories of workers and computerization. We further depart from the existing literature by choosing to use employment share over the wage bill as the dependent variable. This is because of the specific focus of our study, which is to investigate the role of technological change in the employment structure. We will come back to this point later in the methodology section.

2.1 Some Concepts Related to Technological Change

Before stating more precisely the assumptions on which the present study lies, it would be useful to define some concepts and look at the way they interact *theoretically* and thus introduce indicators aiming at measuring their relationship *empirically*. Knowledge, skill and technology are key concepts in this paper. To contribute to production, knowledge must be embodied in people (as skills) and capital goods (as technology). The central assumption of this paper is that to ensure an efficient production process, the two bodies of knowledge must be complementary. Essentially, this means that a change in production recipes involving a new technology paradigm must be accompanied simultaneously by a change in skills; otherwise, a firm would run the risk of being driven out of business.

Technological change as a whole, whether 'embodied' (embodied in new capital equipment) or 'disembodied' (embodied in people)[3], as well as process innovation or product innovation, will likely transform the skill composition of the labour market.

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[3] The distinction between embodied and disembodied technological change is especially important to keep in mind since these two vehicles of technological change are referred to often in the literature and most certainly affect the labour market differently (Betts: undated, 4). Otherwise stated, embodied technological change refers to an investment in new capital in which there is some level of knowledge (or technology). Disembodied technological change refers to the knowledge embodied in people which can potentially be applied (process) or used (product) and can transform the whole economy relatively quickly depending on how this innovation is protected (patent law). Embodied technological change may transform the nature of work in a particular industry but is likely to take time as investment in new capital takes time (Betts: undated, 4) and massive layoffs are likely to be avoided by management. In the present paper, only embodied technology is examined, through computer investment and capital intensity indicators. Computer investment includes both hardware and software and thus some level of embodied knowledge; this knowledge changed tremendously (through software) and came to be processed at an incredibly higher rate (through hardware, which includes microprocessors) over the 1971-1991 period studied here. Capital intensity refers to new capital investment and will provide us with a good approximation of the state of technological change in a given industry. This will be very useful in delineating the impact of other technological equipment and will provide a benchmark for the second paper which will directly tackle the impact of AMTs (Advanced Manufacturing Technologies) in the manufacturing sector. The second paper will also include a comparison between embodied technological change (using R&D/sales as a measure) and disembodied technological change (using input/output data on other commodities) in the manufacturing sector.

The effect of computerization on employment composition is especially interesting given the computer's widespread industrial diffusion, its rapid change in quality over the last two decades and its adoption by a range of workers with quite different sets of skills.

However, it is very important to realize that computing is quite often a complementary activity for a multitude of occupations and industries and, therefore, does not constitute a core activity, thus leaving significant room for other technologies in explaining employment transformation.[4]

2.2 Physical Capital/ Skill/ Technology Nexus

The relationship between skill and physical capital is not necessarily a linear one: it depends in large part on the state of technology. This is the capital/technology/skill nexus, which is worth examining. As stated by Goldin and Katz "physical capital and skill have been shown to be relative complements both today and in the recent past" (1998: 693). They argue in relation to technological change that "the shift to a more advanced technology is associated with increases in both capital intensity and the relative employment of more-skilled workers" (Goldin, Katz: 1998, 703). This implies, as will be seen later, that we cannot analyze the role of capital intensity too narrowly but must examine it within the context of technology intensity.

On the other hand, as Wood (1994) and Goldin and Katz (1996) acknowledge, a complementarity with technology does not always imply an association with skilled workers. Depending on the equipment (physical capital) – the nature of the technology and its rate of change – different categories of workers can be more closely related than others to a given technology.

2.3 Labour-Saving, Labour-Using and Neutral Effect of Computerization

This paper assesses the effect of the diffusion of computer technology on the employment structure. More precisely, we evaluate how investment in computers relative to investment in other machinery and equipment affects the employment structure. The key question in our research is whether the declining demand for goods workers (low-skilled) and the relative

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[4] Once again, it is worth remembering that for this paper, only the computer (hardware and software) commodity is considered, thus excluding the fusion of electronics with other commodities, as in advanced manufacturing technologies. However, as our computer investment variable includes software, the effect of computer intensity on employment structure could also reflect the effect of expert systems software.

increase in other categories of occupations (knowledge, data and management) can be explained by the accelerated diffusion of computers.[5] This leads us to specify four sets of assumptions related to these potential effects.

(i) The first possible assumption is that there is a skill-biased technical change: the increasing use of computers (or change in production techniques) favours some categories of workers (labour-using bias or complementarity). By changing skill requirements in an industry, computerization increases the optimal ratio of some categories of occupations to other categories per unit of output. This change could be related to the increasing complexity of certain types of work which are too tacit to be codified and which require other skills;[6]

(ii) The second possible assumption is that computerization reduces the quantity of a particular category of worker per unit of output given that the core tasks of the workers are codifiable. Automating routine aspects of certain tasks implies that fewer workers in a given occupation will be required (substitution bias or labour-saving bias).

(iii) The third assumption posits a neutral effect, i.e. that the computer plays no role given the highly tacit nature of the tasks performed in an occupation.

(iv) The fourth assumption would be that by transforming the task content of an occupation, it is likely that computerization will not require a change in the number of workers but instead will transform the task content of an occupation either by upgrading or de-skilling work.[7]

With a macroeconomic unit of analysis such as that used in the present study, it is impossible to determine the magnitude of this last effect and this is why only the first three assumptions will be tested in the paper. In fact, only case studies could offer an understanding of the magnitude of skill changes within a single occupation (Cyert, Mowery: 1987, 101).

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[5] It is worth noting that most studies aggregate workers into two groups – production vs. non-production, skilled vs. unskilled, information vs. non-information, and so on. In this paper, high-skilled workers are not exclusively related to a single category, that is, knowledge workers. In our study, skilled workers would be composed of workers from the data and knowledge categories and, to a lesser extent, management workers. For more details on the classification of workers used in this paper, we refer the reader to Lavoie, Roy: 1998.

[6] Please see Lavoie, Roy (1998) for a description of the dynamics of increasing complexity and uncodifiable tasks. See also Levy, Munrane: 1996 who clearly describe uncodifiable tasks as those that involve "making judgment calls" as opposed to routinized tasks, which hardly require judgment and can be performed at low cost. OECD (1996) is another important source.

[7] Braverman was the one who introduced the concept of de-skilling of work, meaning essentially that the skill content of people's jobs is decreasing considerably. Under this label, we also include the upgrading effect. For example, it is likely that secretaries have had to improve their skills over the last few decades to keep abreast of the changes brought by computerization, even though there has been no change in the number of secretaries required in the economy. In other words, the content of the secretary's job has probably changed but followed an upgrading instead of a de-skilling process (Spenner: 1990). In this paper, we do not examine the content of individual occupations but rather the change in the number of different occupations.

Some complementary explanations will also be taken into account. For example, we believe that there are strong inter-industrial differences in the impact of computer investment on employment categories. Are there a higher concentration and an increasing growth of knowledge workers or of data workers within computer-intensive industrial sectors? Although it is generally recognized that computerization is widespread, its contribution to the production processes of different industries can vary enormously and produce different effects on the structure of employment. Another important question regards the role of computerization in the important shift in activities from manufacturing to service industries. Although this question cannot be answered directly, some elements will be introduced in order to disentangle the role of the computer and the shift towards service industries in the upward shift in employment in the Canadian economy.

We also believe that for a given category of workers, even if they are all highly skilled (as in the knowledge category), different occupations may embody different types of skills. It is likely that inter-occupational differences in terms of skills induce a relatively different type of relationship with the use of the computer.

Finally, is there stability in the relationships between occupations and the use of the computer over the two decades covered by the study? We expect different levels of complementarity over time for different occupations given the changing importance of the role of the computer over the last 25 years due to the reduction in price and the improvement in performance. The next section will review some significant changes in the diffusion and use of computers over this period to better understand its employment effects.

One last word about our central assumption: in this study, we look at the magnitude of the relative complementarity of physical capital and computers with different categories of workers. We do not try to account for the potential effects of technological change on wage differentials. In fact, we believe that it would be hard to test the latter hypothesis without using a framework including relative demand and relative supply of skills (Autor, Katz, Krueger: 1997, DiNardo, Pischke: 1996). We will come back to this point later in the methodology section.

3. Evolution of Computer Technology

In the period covered in this study (1971-1991), the labour market showed substantial change, with structural unemployment becoming increasingly severe from one recession to another. At the same time, the skill profile changed too, with knowledge workers assuming a dominant position in terms of growth despite its small share. This was also the period during which computerization recorded the most rapid growth as technology advanced by leaps and bounds. Although these two decades were an intensive period of change in terms of computerization, the idea of building a computer was born much earlier, back in Babbage's time. In this section, we give a succinct overview of the history of computer and software development, in order to set up the context and assess the magnitude of the phenomenon in recent years.

Computerization is at the core of the information and communication technology (ICT) revolution. In fact, it is the convergence of computer and telecommunication technology which has led to ICTs (Freeman, Soete: 1997, 160).[8] This new family of technologies has enormous impact on the institutional and organizational infrastructure. This is "a new techno-economic paradigm affecting the design, management and control of production and service systems throughout the economy, based on an interconnected set of radical innovations in electronic computers, software engineering, control systems, integrated circuits and telecommunications, which have drastically reduced the cost of storing, processing, communicating and disseminating information" (Freeman, Soete: 1994, 42).

Electronic technologies have changed tremendously during the last three decades, with a substantial impact on prices and on the user-friendliness of these technologies. It is worth giving an historical overview of the computer, since this evolution has been accompanied by changing employment profiles and labour market conditions.

We must go back to the 1830s to trace the initial features of the modern computer through two machines that Babbage developed but failed to perfect, given the inadequate components and techniques of the time. These were a special purpose calculating machine and a general machine.

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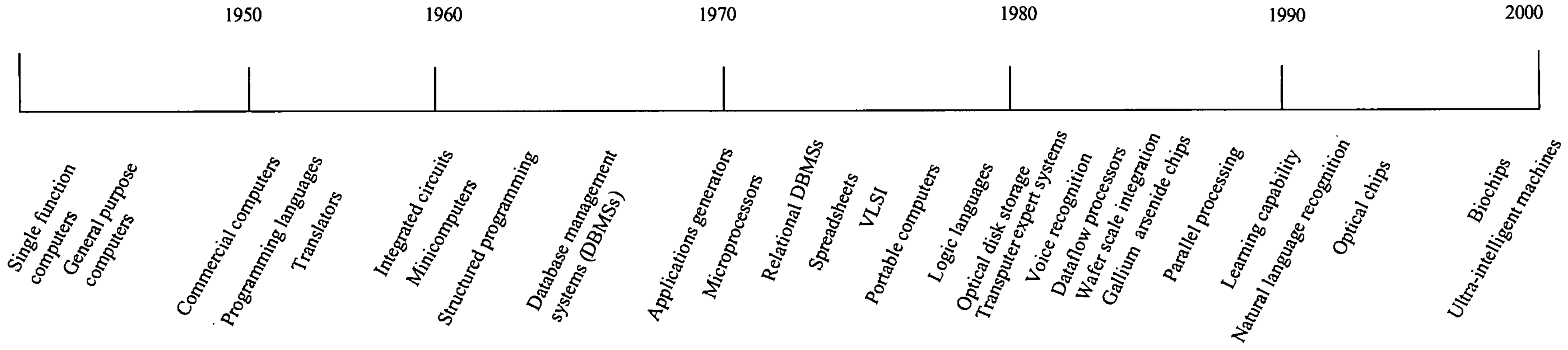
[8] A companion paper on the manufacturing sector will look at an extension of the electronics revolution, that is, the mechatronics revolution (i.e. advanced manufacturing technologies), and its impact on the employment structure.

Figure 1
Computer Technology Evolution



Source: Based on information taken from Freeman, Soete: 1994

Essentially, although they were mechanical and electromechanical computers – slow by electronic standards[9] – the conceptual idea of the universal computer and the understanding of its possibilities were present in these two prototypes. However, the computer as known today is a product of the second half of the twentieth century.

The contemporary computer is the result of an astounding process of technological evolution – from valves or vacuum tubes to transistors[10] in the 1950s, integrated circuits in the 1960s, large scale integration in the 1970s, very large scale integration and, ultimately, the workstations and PCs that have recently been gaining large market shares.[11]

It is worth remembering that prior to 1950, there were no expectations of commercial demand for electronic computers and thus no private funds were committed. However, during the 1940s, Bell Laboratories, the only industrial laboratory conducting basic research, sponsored a research program in solid state physics that led to the transistor. During and after World War II, it was essentially military interests that drove research and development. The Korean War led to IBM involvement.

The first generation of commercial computers, developed in the 1950s using tube technology, was displaced in the early 1970s by the microcomputer due to the advent of the microprocessor or computer on a chip. Although successful, the first generation had many problems of size and reliability, given the large number of tubes involved, requiring high power consumption and generating a great quantity of heat. The microprocessor made it possible to substantially reduce the size and cost of the hardware, which resulted in an increasing, though not widespread, diffusion of personal computers in households and businesses in the early 1970s. At that time, IBM faced serious competition, mainly because of its failure to recognize the way the computer market was changing with the advent of the personal computer. IBM remained focussed on large mainframe computers while a number of new players like NEC and Toshiba were entering the personal computer market.

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[9] According to Freeman and Soete (1997: 172), "the first electronic machines were over a thousand times faster than the electromechanical ones for both multiplication and addition".

[10] These are 'active' components influencing the flow of electricity through the circuit.

[11] By 1984, PCs and workstations had more than 30 percent of the market (Fransman: 1994).

> … in the 1970s and 1980s the scale of their [personal computers] diffusion, the reduction in their costs, the immense range of potential applications and the convergence with telecommunication technology led to the structural crisis of adjustment which we are now experiencing in the 1990s (Freeman, Soete: 1994, 47).

The pervasiveness of the microelectronic revolution was so vast affecting all spheres of economic life – from automation and control of industrial processes to service industries and, finally, domestic tasks – and, consequently, impacting the employment structure. Moreover, the development of the "transputer" and parallel processing as early as the 1980s enabled the rise of network computing, which was to expand tremendously in the future.

Software developed in parallel and interactively with hardware was characterized by changing strategies on the part of major companies active in both the production of hardware and the development of software as well as those engaged in the supply of programming and consulting services.[12]

> In particular, it is important to distinguish the microelectronics revolution from the software revolution...In the 1970s, the so-called microelectronics revolution began with the spectacular achievements in semiconductor technology: in particular, the development of the microprocessor and the capacity to store and manipulate vast quantities of information on a small and increasingly cheap electronic chip (...) Perhaps even more important, we have seen the equally spectacular advances in software technology (i.e., techniques for manipulating information), which had previously been developed and closely controlled by manufacturers of computer hardware. The steep reduction in hardware costs and the emergence of cheap standard products (such as personal computers) has resulted in the emergence of two other major sources of software technology: independent software suppliers (large ones like Microsoft, and many small ones developing applications software) and operators of large-scale systems (e.g., banks, retail chains, airlines). As a result, the technological trajectories of firms and countries in their development of software have progressively become de-coupled from their trajectories in computer hardware (Pavitt : 1998, 565-566).

Moreover, with a trend first toward customization and later toward standardization, very different industries were involved in the development of software and the supply of software services, eventually leading to a shift of computer scientists toward the service sector in the late 1980s.

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[12] For a comprehensive view of the evolution of hardware and software in the context of industrial transformation, we refer the reader to Steinmueller (1995), who provides a good review of the United States software industry.

At the beginning of the 1980s, the personal computer did not have the performance to replace mainframe computers and companies still had to maintain and expand mainframe software applications, which involved keeping an internal technological capability. However, the rapid expansion of computer operations quickly outpaced the development of these internal capabilities.

> The continued growth in the intensity of computer operations during the 1970s and 1980s provided a growing challenge for internal development capabilities. In many cases, internal bureaucracies ossified, or were simply unable to keep up with the pace of technological change. Accordingly, firms began to reconsider the make or buy decision for their entire data processing activity. If another firm could provide the technological knowledge and human resources to implement specialized software solutions, choose among complex competing hardware offerings, and deliver useful information services to internal users, why not buy these services rather than produce them in-house? The growing complexity of data processing technologies and markets pushed companies toward the "buy" solution and a number of companies emerged to satisfy this demand (Steinmueller: 1995, 35).

Following this 'contracting-out' trend, the end of the 1980s brought major advances in linking personal computers into extensive networks, which reduced the need for external computing services.

We are still only seeing the beginning of the computer revolution and the associated employment restructuring. Fuzzy logic – combining revolutionary computer technology with a neural network which imitates the human brain – is going to completely revolutionize the electronic computer and the way we work as well as the way we go about our daily activities.

Indeed, the point here is to realize that while the impact of computerization on the employment structure has been substantial during the last two decades or so, in view of the tremendous changes yet to come in the nature of computer technologies we may assume that even greater employment restructuring lies ahead. As explained earlier, our assumption is that although computer technology may have allowed for more productive processes to arise in mature industries, productivity enhancement is not the only means by which the computer transforms the employment structure and this is probably why in some industries there is a significant productivity lag. In fact, by providing more efficient ways of doing things, computerization allows workers to reach the very frontier of knowledge and therefore increases the complexity of problems to be solved and, consequently, the complexity of tasks, thus reducing the rate of productivity (Lavoie, Roy: 1998).

> I.T. has fundamentally enhanced the conduct of scientific research, data modeling and analysis, and the creation of scientifically derived knowledge (...) High-speed computing and advanced software applications have also enhanced the analysis of scientific data and drastically shortened the amount of time required to perform certain scientific tasks (National Science Foundation: 1998, 8-18).

However, this does not imply that computers are substituted for the scientists. Let us take an example to illustrate this point. While the increasing productivity of biologists in the gene mapping related to highly advanced computational programs should eventually lead to a reduction in the number of biologists, we might, on the reverse, observe an increasing demand for these specialists. This can be explained by the drop in the codified portion of their tasks counterbalanced by the growth in the tacit portion due to the incapacity of reducing the complexity of the research. This is a virtuous circle according to which the more the computer reduces the load of codified knowledge, the more the quantity of tacit activities may tend to increase.

4. An Evolving Industrial Structure, Capital Intensity and Computer Intensity Across Industrial Sectors

The well-documented non-homogeneity and differentiation of technological activities across industrial sectors are mainly due to the variety of sources and effects of technological change by industrial sector.[13] This prompted us to develop a taxonomy of industrial sectors that could address this diversity to more accurately explain the variety of employment effects induced by technological change in the economy.

As we began with a restricted thirty-industry aggregation of computer investment data, we had to rely on a rather coarse taxonomy. Ideally, we would have liked to have been able to classify industrial sectors in terms of their core technological activities, thus allowing us to better understand their contribution to the nation's technological progress. However, the limited number of industrial sectors forced us to disaggregate the whole industrial system into four categories – primary, manufacturing, service and public sector. Working from published estimates of the rates of penetration of technologies and industrial spending on R&D, manufacturing was further disaggregated into low-, medium- and high-tech on the basis of the technology intensity of each industry's activities (Lavoie, Finnie: 1996).[14]

What this taxonomic exercise shows is that the Canadian economy is increasingly becoming a service-related one. Figure 2 illustrates the clear fact that the share of total employment for the service sector is significantly higher than for other sectors and increasingly so. While the service-economy trend is widespread across countries, it is rather difficult to pinpoint the reasons for this shift (OECD: 1996, Lavoie, Roy: 1998, Lavoie, Finnie: 1998, Soete: 1995, O'Farrell: 1995, Osberg: 1989, Howe: 1986, National Science Foundation: 1998). It may be due to an expansion of demand for these services or might be explained by an increased 'contracting-out' strategy in other sectors. It is beyond the scope of the present paper to disentangle the reasons underlying

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[13] Concerning the variety of industrial technological activities, see among others, Napolitano (1991) and Pavitt (1984).

[14] Our industrial taxonomy resulted in six industrial sectors – primary, manufacturing-high, manufacturing-medium, manufacturing-low, service and public sector. It is worth noting that the aircraft and parts industry (SIC-321) was excluded from the high-tech manufacturing sector despite its high technology intensity. This is due to the aggregation level of computer investment data used in this paper which is at the two digit level and thus forces us to include this industry into the medium-tech manufacturing as it was impossible to separate it from the whole

this shift but we believe that the accelerating rate of technological change may be partly responsible or, as stated by the National Science Foundation, may have acted as a precondition of the growth in service industries, being instrumental to the delivery of many services (N.S.F.: 1998).[15]

Figure 2a
Employment Shares by Industrial Category: 1971-1991

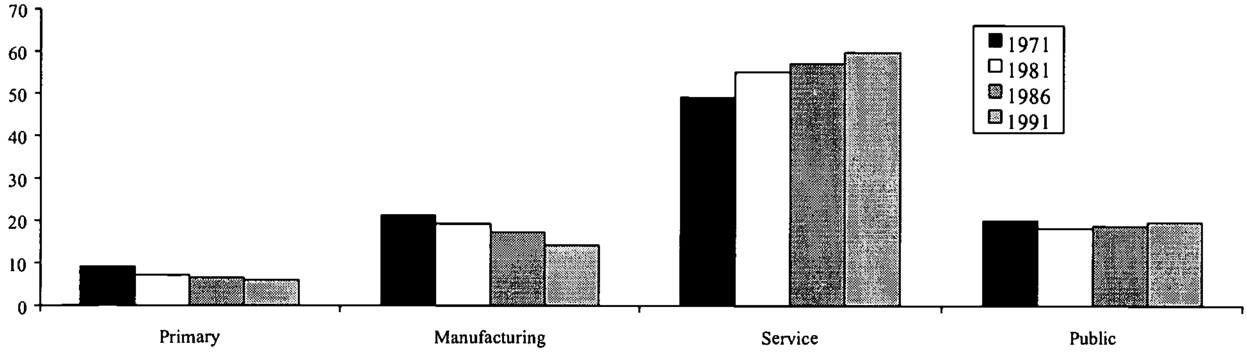
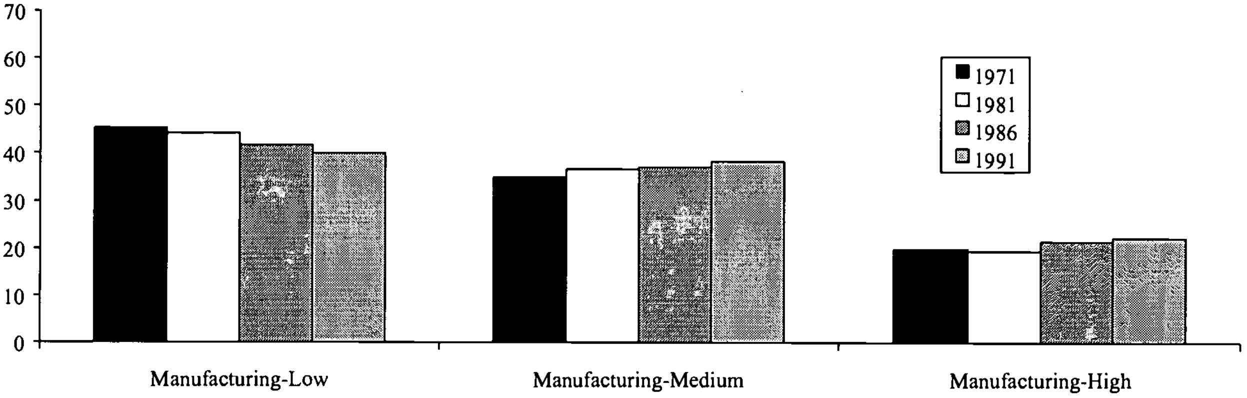


Figure 2b
Employment Shares in Manufacturing Sectors: 1971-1991



Source: Census

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transportation equipment industry (SIC-32). This introduced some bias but, even considering the lack of refinement, the classification proved to be quite useful. See the appendix for a complete description.

[15] In fact, we performed a test, integrating intermediary purchases of business services over total purchases into the regression, in order to assess the magnitude of this shift. We saw a significant positive effect with knowledge workers in 1986 and 1991 and a significant negative effect with goods workers for the same period for the whole economy. These results do not change the effect of the computer. More work should be done to better isolate the contracting-out effect from other effects and understand the magnitude of the shift toward the service sector.

Moreover, it appears quite clear that the core activities of service industries cannot be significantly reduced, given the largely tacit nature of knowledge in these industries. In other words, while the manufacturing sector mostly embodies codifiable knowledge, in the service sector, the knowledge is mainly tacit, which tends to enlarge this industrial sector relative to other industrial categories. As stated by Freeman and Soete, "the implications for this continuous shift in value from manufactured goods embodying increasing amounts of 'codifiable' knowledge towards service-based 'tacit' knowledge activities is typical of the new emerging Information Society" (Freeman, Soete: 1997, 406). Therefore, even if computer intensity is greater in the service sector than in the primary or manufacturing sectors, it cannot significantly substitute for the tacit portion of knowledge activities.

Along with an increasing rate of employment growth in the service sector, we observe a decreasing rate in the primary and manufacturing sectors, while in the public sector the pattern of employment is fairly stable overall (after a slight dip in 1981 the share of employment gradually rises again and by 1991 is just a little less than it was in 1971).

Looking more closely at the manufacturing sector, it is also worth noting the ever important role of low-tech industries in the Canadian economy, although their share slightly decreased over the two decades. High-tech manufacturing still represents a very small share of total employment. It sums that, to some extent, computerization has helped to transform industries inherited from the past industrial era (Steinmueller: 1995).

Capital Intensity and Computer Intensity Across Industrial Sectors

While technology is an important determinant of capital intensity, there are other explanations for poor productivity of the stock of capital: for example, management may deploy the workforce inefficiently, or restrictive practices on the part of the workforce may lead to lower value added. Nonetheless, it is important to better understand the relationship between technology and capital. According to Pasinetti,

> At the sectoral level, each capital/output ratio is essentially determined by *technology*. In more practical terms, if, at any given point of time, the capital/output ratio in a sector such as 'house renting' is of the order of 100 times larger than in a sector such as 'clothing', the reason simply is that *technology* is such that the minimum-cost production process requires, in the

> house renting sector, a capital/output ratio which is 100 times larger than in the clothing sector (Pasinetti: 1981, 216-17).

The rationale would be that for a given capital intensity level, there should be a given level of employment. However, our explanation is that capital does not substitute for labour directly but does so through technology, with some types of employment being complementary to high capital intensity. In other words, instead of following the reasoning according to which capital intensity reveals the productivity of capital, we follow the rationale according to which there should be a link between capital intensity, technology intensity and human capital intensity (e.g., high-skilled workers). As was expressed by Howitt at a conference in Ottawa, "R&D tends to be a capital-intensive activity, in terms of both human and physical capital". Interpreting capital intensity in the light of technological change becomes rather complicated and this is why even though capital intensity can tell us something about the state of technology in a particular industry, the addition of other technology variables is very useful.[16]

One important observation in Figures 3a, b, c and d is that for the entire economy, capital intensity remains quite stable over time.[17] However, at the sectoral level there are some important differences in capital intensity.[18] The primary sector has the highest intensity (although this declines sharply over time), followed by the public, service[19] and manufacturing sectors.

In the manufacturing sector, the capital intensity is up slightly in 1991 reflecting the large increase for medium-tech industries. Low-tech industries also showed a slight increase for the last year whereas the capital intensity of high-tech industries decreased.

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[16] For a highlighting discussion in the role of capital in technological change and economic growth, see Papaconstantinou *et al* (1996).

[17] As a whole, capital intensity had an average annual rate of growth of 0.2 percent while the rate of growth of computer intensity reached 3.4 percent between 1971 and 1991 (not shown on the tables).

[18] The capital intensity variable is constructed as capital stock over value added (see chapter 6 of this paper for further information). Value added (GDP at factor cost) used for the public sector differs from that one used in the private sector forcing us to be cautious in doing inter-sectoral comparisons. GDP originating in the public sector includes only labour income (wages, salaries and supplementary labour income) plus depreciation of capital stock (Statistics Canada, cat. 15-510).

[19] It is worth remembering that utilities are included in the service category. Being very capital-intensive, they change the whole service category capital intensity level somewhat. When utilities are included, the capital intensity of the whole service sector is 0.88 in 1971 and 1.01 in 1991, while it is 0.58 in 1971 and 0.69 in 1991 if utilities are excluded. See Appendix for more details on capital intensity across disaggregated industries.

Figure 3a
Computer Intensity by Sector (C/I)

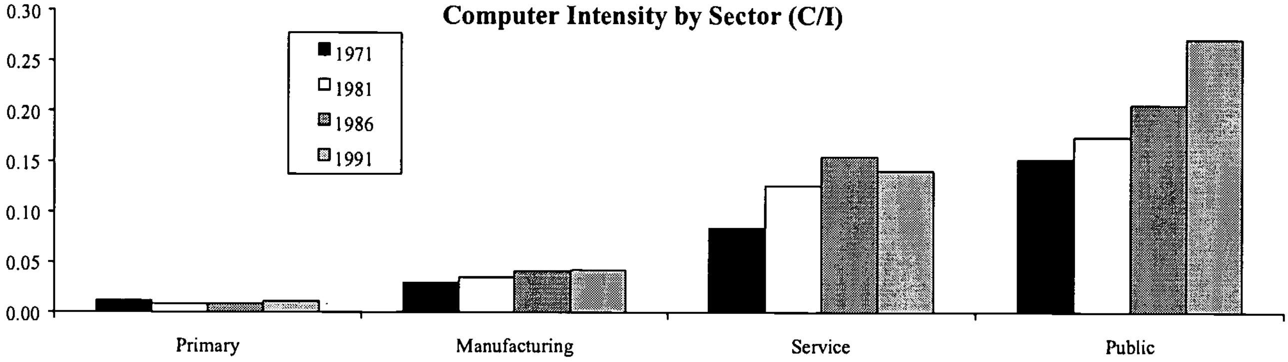


Figure 3b
Capital Intensity by Sector (K/V.A.)

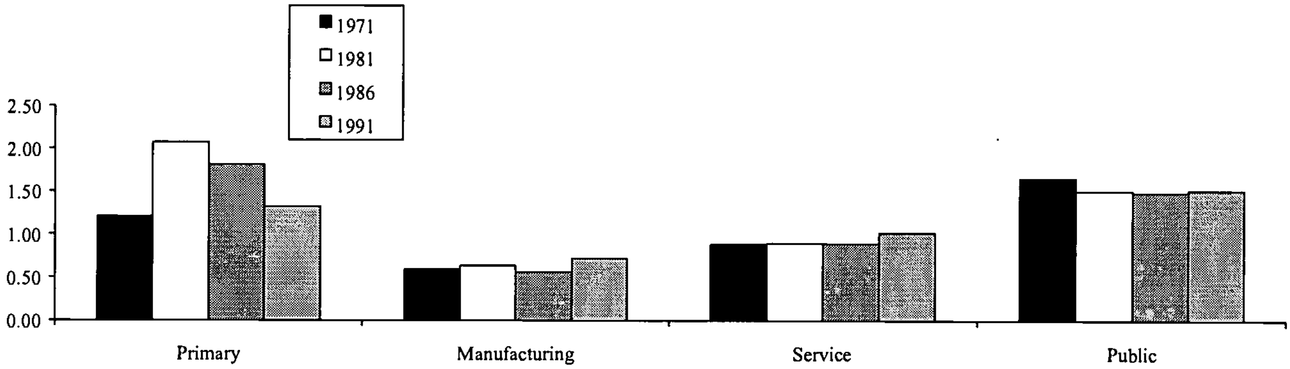
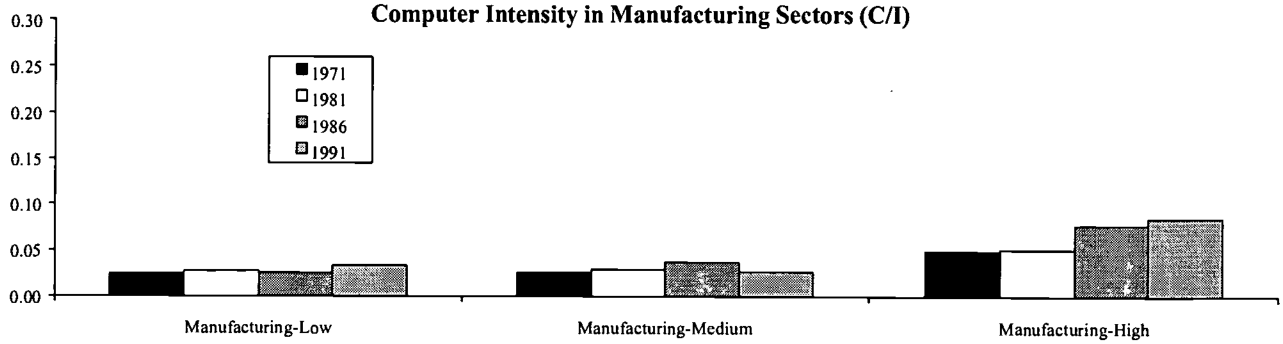
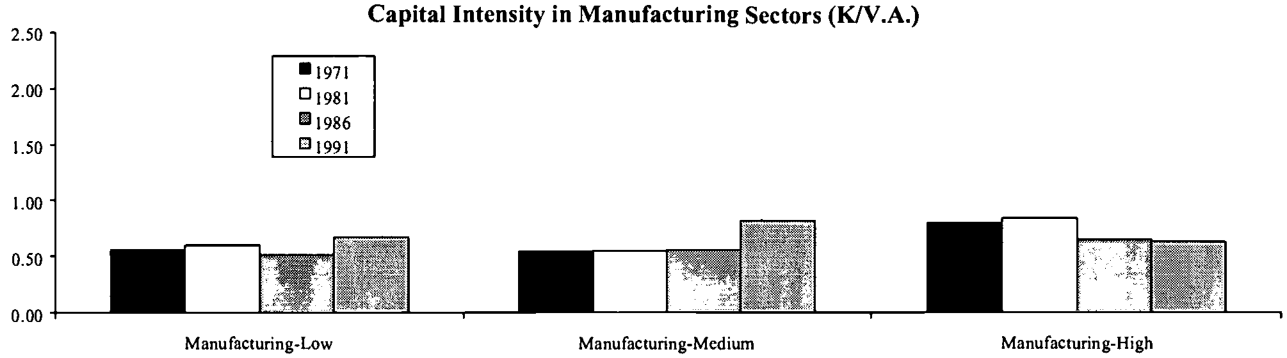


Figure 3c
Computer Intensity in Manufacturing Sectors (C/I)



Source: Refer to Section 6.2 for data description

Figure 3d
Capital Intensity in Manufacturing Sectors (K/V.A.)



Source: Refer to Section 6.2 for data description

Are the most capital-intensive industries the most computer-intensive ones? Across large industrial sectors, we find increasing computer intensity over time while in general capital intensity is fairly stable except in the primary sector. A second observation is that the primary sector has a very low computer intensity while the capital intensity is high. The public sector is both the most capital-intensive and the most computer-intensive, with computer intensity increasing rapidly. Disaggregating the manufacturing sector once again reveals some differences in the trends, but the magnitude for all sectors is basically similar. The last point is related to high-tech manufacturing, where the two intensity measures are clearly polar opposites with an increasing computer intensity and a decreasing capital intensity; this leads us to think that technologies other than computerization are involved in this sector.

Having described these intensity trends across industries, we shall see in the last section how they affect different categories of employment.

5. Employment Structure Transformation

In a previous study (Lavoie, Roy: 1998), we observed a high growth rate for knowledge workers although varied across knowledge sub-categories. On the basis of a decomposition accounting model, three sources of employment transformation were examined and, although this assertion was not assessed directly, the large substitution effect led us to believe that technological change plays an important role. In fact, the impact of technology can be manifold: substituting some groups of workers for others, increasing productivity but also the quality of and demand for sophisticated new products, and so on. While, typically, a high growth rate for productivity is related to decreasing employment, especially in the case of mature and declining industries, "the evidence is strong that with new products and services [there is] a 'virtuous circle' [where] high output growth, high employment growth and high productivity growth tend to go together and to reinforce each other" (Freeman, Soete: 1994, 59).

Looking at Tables 1a and 1b, it can be seen that the strongest rate of employment growth over the 1971-1991 period took place in the service sector, followed by the public sector, thus reflecting the shift from manufacturing to service. The primary and manufacturing sectors had slower but quite similar growth rates – 0.3 and 0.4 percent respectively over the whole period (not shown on the tables). Comparing the two decades, it is worth noting that the public sector alone had a larger increase during the last period while all the other sectors had a more significant rate of employment growth during the first decade.

It is also important to note that in the second decade, especially the last half, manufacturing showed a negative growth in employment, which might also reflect the general shift from manufacturing to the service and public sectors. Finally, employment growth in the primary sector was stable over the two decades.

Table 1a
Employment by Category of Occupation, 1971-1991

Primary

	In Thousands				Average Annual Rate of Growth	
Occupational Group	1971	1981	1986	1991	1971-81	1981-91
Knowledge		26.1		33.4		2.5
	1.7		1.4		-2.9	
Applied Sc		8.0		10.1		2.3
	4.8		9.2		6.5	
Computer		1.9		3.3		5.9
	2.6		6.9		8.3	
Management		47.7		91.1		6.7
	0.7		3.6		16.3	
No-Tech Mgt		44.6		86.8		6.9
	33.7		66.5		6.5	
Service		10.2		13.7		3.1
	661.6		612.5		-0.7	
Total		**764.3**		**788.1**		**0.3**

Manufacturing

	In Thousands				Average Annual Rate of Growth	
	1971	1981	1986	1991	1971-81	1981-91
Knowledge	78.3	98.6	116.6	127.4	2.3	2.6
Pure Science	4.9	5.0	6.2	6.3	0.3	2.3
Applied Sc	0.8	1.2	1.5	2.1	4.0	6.0
Engineering	30.0	36.1	41.4	43.9	1.9	2.0
Computer	6.7	10.6	15.5	17.8	4.6	5.4
SSHs	35.9	45.7	51.9	57.2	2.4	2.3
Management	34.6	120.5	148.7	175.3	13.3	3.8
S+T Mgt	6.8	38.8	40.7	45.1	19.0	1.5
No-Tech Mgt	27.8	81.7	108.0	130.2	11.4	4.8
Data	391.6	401.9	392.7	393.8	0.3	-0.2
Service	44.2	40.8	36.4	33.0	-0.8	-2.1
Goods	1173.6	1385.0	1319.7	1128.7	1.7	-2.0
Total	**1722.4**	**2046.9**	**2014.1**	**1858.1**	**1.7**	**-1.0**

continued...

Table 1a *(cont.)*

Service

	In Thousands				*Average Annual Rate of Growth*	
	1971	1981	1986	1991	1971-81	1981-91
Knowledge	214.2	377.4	475.5	621.5	5.8	5.1
Pure Science	3.4	5.9	8.1	11.5	5.6	6.9
Applied Sc	21.7	30.8	36.5	41.9	3.6	3.1
Engineering	38.6	64.5	67.5	93.4	5.3	3.8
Computer	10.3	33.2	58.4	94.4	12.4	11.0
SSHs	140.1	243.0	305.0	380.4	5.7	4.6
Management	79.6	439.3	579.2	760.7	18.6	5.6
S+T Mgt	5.5	33.9	37.7	54.0	19.8	4.8
No-Tech Mgt	74.0	405.4	541.5	706.7	18.5	5.7
Data	1699.8	2469.9	2750.4	3145.2	3.8	2.4
Service	673.3	982.2	1188.8	1384.6	3.8	3.5
Goods	1334.5	1634.3	1713.2	1884.8	2.0	1.4
Total	**4001.4**	**5903.1**	**6707.1**	**7797.0**	**4.0**	**2.8**

Public Sector

	In Thousands				*Average Annual Rate of Growth*	
Occupational Group	1971	1981	1986	1991	1971-81	1981-91
Knowledge	121.3	175.1	205.6	256.1	3.7	3.9
Pure Science	14.9	18.0	21.0	26.0	1.9	3.8
Applied Sc	30.4	37.3	42.3	51.7	2.1	3.3
Engineering	22.6	27.2	30.1	37.8	1.9	3.4
Computer	6.2	13.6	20.2	28.4	8.1	7.6
SSHs	47.1	79.0	92.0	112.1	5.3	3.6
Management	81.2	139.0	181.2	233.3	5.5	5.3
S+T Mgt	5.1	11.1	13.8	19.6	8.1	5.9
No-Tech Mgt	76.1	128.0	167.3	213.6	5.3	5.3
Data	815.5	1018.1	1089.4	1257.5	2.2	2.1
Service	457.9	451.4	560.0	615.8	-0.1	3.2
Goods	162.1	168.2	169.7	199.4	0.4	1.7
Total	**1638.0**	**1951.7**	**2205.9**	**2562.1**	**1.8**	**2.8**

Source: Census

Disaggregating this picture into four broad industrial sectors reveals some differences in the patterns of growth of different worker categories over time relative to what occurred in the aggregate economy.[20] Let us more closely examine the occupational patterns of industrial groups and then compare the trends to ascertain the variety of skills required in these sectors.

On balance, we can say, at this point, that there was more job creation than job destruction while the skill profile changed considerably during these two decades. The following section will summarize these transformations across groups of workers. First, a few words about our occupational classification in relation to the computerization process, in order to better understand the industrial distribution of these categories of workers and, later in the paper, their association with the computer.

The occupational classification used in this paper is the same as that used in Lavoie, Roy: 1998. The total 499 occupations (4 digit SOC-1980 codes) were aggregated into five broad occupational categories – knowledge, management, data, services and goods. This is a useful classification especially in relation to the impact of computerization. For example, the knowledge category is made up of workers whose core tasks are to produce new ideas; consequently, the role of creativity is important and the computer could hardly serve as a substitute. However, the complementary tasks of these workers are frequently supported by the computer and computerization has even indirectly helped knowledge workers in their core activities by speeding up and facilitating calculations, and so on. For data workers, on the other hand, core tasks include data storage and retrieval, which are amenable to computerization given their codifiable nature. Unlike knowledge workers, data workers carry out routine core activities and tacit complementary activities, including, for example, judgment activities.

The core tasks of a manager are hardly routine, as they require judgment and some creativity for planning, directing, reading reports, and so on. The complementary tasks could nonetheless be more routine as they might consist in writing up bills and invoices that can be made a standard procedure with computerization. The core tasks of service workers, which consist in providing

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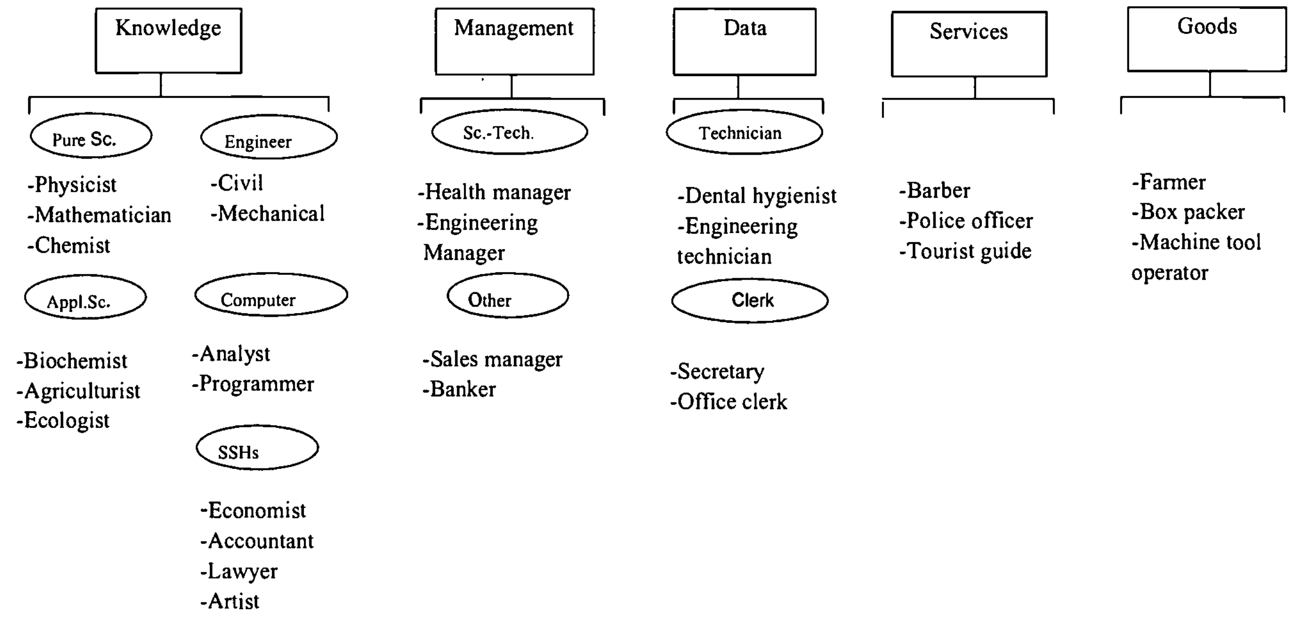
[20] The huge variety of occupations across industries is important to take into account in this paper. For example, we can find a large concentration of data occupations in some specific industries in the service category while the concentration will be very low in the construction industry, even though it, too, is part of the service category. In other words, our four broad categories of industries are not homogeneous in terms of the occupations they include, and a finer disaggregation would allow a better understanding of the employment structure. This is a limitation of macroeconomic studies: we lose precision for the sake of broader scope.

personal services, are built on experience in a sort of learning-by-doing process and, consequently, are highly tacit. Finally, goods workers' core tasks are composed of highly routinized activities, especially in the manipulation and production of goods, and are choice candidates for expert systems software. However, this is less true for those goods workers who are involved in transportation. In general, the complementary tasks of these workers are minimal.

Figure 4

Occupational Classification



Note: Occupational titles included are examples only.

Source: Lavoie and Roy (1998)

Table 1b

Employment by Category of Occupation in Manufacturing Sectors, 1971-1991

Manufacturing-Low						
	In Thousands				*Average Annual Rate of Growth*	
Occupational Group	1971	1981	1986	1991	1971-81	1981-91
Knowledge	19.4	22.5	24.6	26.1	1.5	1.5
Pure Science	1.6	1.4	1.6	1.5	-1.4	0.8
Applied Sc	0.3	0.6	0.8	1.0	6.6	4.7
Engineering	6.6	7.4	7.4	7.9	1.1	0.7
Computer	1.3	2.4	3.2	3.7	6.5	4.3
SSHs	9.5	10.7	11.5	11.9	1.2	1.1
Management	12.8	44.2	49.6	58.1	13.2	2.8
S+T Mgt	2.5	15.3	14.7	15.8	20.0	0.3
No-Tech Mgt	10.3	28.9	34.9	42.3	10.9	3.9
Data	141.8	140.5	129.4	125.6	-0.1	-1.1
Service	24.1	23.0	19.8	17.6	-0.5	-2.6
Goods	581.3	671.6	615.6	513.2	1.5	-2.7
Total	**779.3**	**901.8**	**839.0**	**740.6**	**1.5**	**-2.0**

Manufacturing-Medium						
	In Thousands				*Average Annual Rate of Growth*	
Occupational Group	1971	1981	1986	1991	1971-81	1981-91
Knowledge	26.6	33.3	38.8	44.8	2.3	3.0
Pure Science	1.0	1.0	1.2	1.3	0.3	3.3
Applied Sc	0.2	0.2	0.3	0.5	4.0	7.5
Engineering	13.2	15.8	18.6	22.1	1.9	3.5
Computer	1.9	3.4	4.7	5.7	4.6	5.3
SSHs	10.2	12.9	14.0	15.2	2.4	1.6
Management	12.0	42.5	52.7	64.4	13.3	4.2
S+T Mgt	2.5	14.1	15.2	17.4	19.0	2.1
No-Tech Mgt	9.6	28.4	37.5	46.9	11.4	5.2
Data	127.2	142.4	136.2	141.6	0.3	-0.1
Service	14.1	12.5	11.3	10.5	(0.8)	-1.7
Goods	422.4	519.0	505.5	445.9	1.7	-1.5
Total	**602.3**	**749.6**	**744.5**	**707.3**	**1.7**	**-0.6**

continued...

Table 1b *(cont.)*

Manufacturing-High

	In Thousands				*Average Annual Rate of Growth*	
Occupational Group	1971	1981	1986	1991	1971-81	1981-91
Knowledge	32.3	42.8	53.2	56.5	2.9	2.8
Pure Science	2.2	2.7	3.4	3.4	1.7	2.6
Applied Sc	0.3	0.3	0.5	0.6	1.7	7.5
Engineering	10.1	13.0	15.4	13.9	2.5	0.7
Computer	3.5	4.7	7.7	8.4	3.1	5.9
SSHs	16.2	22.1	26.4	30.1	3.2	3.1
Management	9.8	33.8	46.4	52.8	13.2	4.6
S+T Mgt	1.9	9.4	10.9	11.8	17.4	2.4
No-Tech Mgt	7.9	24.5	35.5	41.0	11.9	5.3
Data	122.7	119.1	127.1	126.5	(0.3)	0.6
Service	6.1	5.3	5.2	4.8	(1.2)	(1.1)
Goods	169.9	194.4	198.5	169.6	1.4	(1.4)
Total	**340.8**	**395.4**	**430.5**	**410.2**	**1.5**	**0.4**

Source : Census

5.1 Management Workers' Employment

As expected, the management group had the strongest rate of growth over time and across sectors. Compared with other sectors, managers in the non-business (public) sector showed constant growth in employment over time although they exhibited the lowest rate over the two decades. While all other sectors saw a substantial increase in the first decade,[21] this industrial category did not follow exactly the same pattern.

Although the number of science and technology managers is consistently lower than the numbers for other managers across industrial groups, their rate of growth is considerably higher, especially between 1971 and 1981. It is worth noting, though not surprising, that science and

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[21] Although some portion of this increase is real, it is however important to note the bias introduced by the coding changeover from OCM to SOC between 1971 and 1981. We refer the reader to a Statistics Canada staff report (Montigny: 1988), entitled *An Evaluation of Occupational Data from the 1981 Census,* by the Labour and Household Surveys Analysis Division, which explains the reasons behind the rapid rise in management-related occupations between the two censuses. Suffice it to say for now that the main reasons were (*i*) a change in administrators' tasks which led to more frequent use of the term "manager" and (*ii*) less restrictive use of salary limits in 1981 than in 1971. In this report, it is also reported that the French version of the coding manual introduced a bias as well.

technology managers make up a larger proportion of managers – about 25 percent of total management – in the manufacturing sector than in other sectors, where they account for less than 10 percent on average.

5.2 Knowledge Workers' Employment

The most knowledge-intensive sector is the public sector, followed by the service sector, while manufacturing comes last. The highest rate of growth for these workers was observed in the first decade for the primary industries group (with 6.1 percent) and the lowest rate of growth was in the manufacturing sector. While the other three industrial categories had a fairly stable rate of growth over the two decades, the primary sector experienced a decline in growth during the second decade. As a whole, knowledge workers represent a very small portion of total employment, that is, less than 10 percent in all industries.

5.2.1 Pure Science

Finding pure scientists in larger numbers in the public sector does not come as a surprise considering that education and hospitals are included in this category. It is rather encouraging to see that their rate of growth almost doubled from the first to the second decade in this sector, although it remained below the rate for the entire knowledge category for the whole period. The second largest proportion of pure scientists is found in high-tech manufacturing and it rose from 1971 to 1991.

Although they represent only a tiny group of workers in the service sector, this is where pure scientists registered the most substantial rate of growth, especially in the later years, probably reflecting the increasing importance of contracting-out since the growth was in consulting firms and in FIRE (Finance, Insurance and Real Estate).[22] We should probably interpret this increase as an indicator of health if we follow the reasoning of the National Science Foundation, which in its latest report, said that "analysts look to service sector employment as a leading indicator of the health of the S&E (science and engineering) labor market, given the economic shift from a

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[22] This significant increase is mainly due to occupation SOC-2181: Actuaries, Statisticians, and Mathematicians, with an average annual rate of 4.5 percent between 1971 and 1991 in FIRE, and SOC-2189: Occupations in mathematics, n.e.c. In 1971, there were no workers in the latter occupations in FIRE while they numbered 745 in 1991.

manufacturing to a service-oriented base" (NSF: 1998, 3-17). One final point of interest is pure scientists' decreasing rate of growth in the primary sector between 1971 and 1981.[23]

5.2.2 Applied Science

Again, it is no surprise that the largest number of applied scientists is found in the public sector.[24] Although they substantially outnumber pure scientists in the service sector, their rate of growth there is approximately half as high, and this sectoral deviation increases over the two decades. Contrary to pure science, applied science makes up an important and increasingly large contingent in the primary sector and also expands quite rapidly in the manufacturing sector (medium- and high-tech manufacturing)[25] especially in the second decade, far surpassing the rate of growth for engineering workers.

5.2.3 Engineering

Although the largest concentration of engineers is in the manufacturing sector, this is the industrial category where the rate of growth for these workers was lowest for the whole period. This could partly be explained by greater recourse to contracting-out for engineering expertise. Manufacturing firms probably prefer to hire the services of consulting engineering firms, which allows them to keep a certain flexibility to hire and fire and also remain state-of-the-art in all engineering fields. (They probably use the same strategy for computer scientists, as will be seen below, since computer science's rate of growth is significantly lower in manufacturing than in other industrial groups.) This would be consistent with the significant boom for this category of workers in the service sector, in which consulting engineering firms are included. Between 1971 and 1991, the primary sector registered a considerable increase in this expertise, although the rate of growth declined substantially during the second decade.

It is worth noting the fact that the rate of growth of engineers across sectors was generally lower than the rate of growth of the whole knowledge category but higher than the rate of growth of total employment.

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[23] This drop is mainly due to the decline in occupation SOC-2119: Physical Sciences, n.e.c. (e.g. prospectors, explorers, physical metallurgists, and so on) in Mining between 1971 and 1981.

[24] After this section, we consider pure and applied science together, given the small size of these occupational groups.

[25] The average annual rate of growth of SOC-2133: Biologists and Related Occupations in high-tech manufacturing between 1981 and 1991 was 8.5 percent. For medium-tech manufacturing, the growth was mainly in occupation OC-2131: Agriculturists and Related Scientists, with an average annual rate of growth of 14 percent between 1981 and 1991.

5.2.4 Computer Science

Computer scientists have one of the highest rates of growth of all categories of workers across all industrial sectors, occasionally sharing this position with the management category. It was the service sector that saw the most significant increase in computer scientists from 1971 to 1991 and this was fairly stable over time, although the rate fell off slightly between 1981 and 1991 from 12.4 percent to 11 percent. In this sector, the computer science group, which was about 27 percent the size of the engineering category of workers in 1971, actually outnumbered the engineering group by 1991. The situation is nevertheless quite different for the manufacturing sector in which the engineering group is 2.5 times larger than the computer science group. However, the rate of growth for computer scientists is more than twice as high as the rate of growth for engineers for the entire period – despite the fact that this was the sector with the lowest rate of growth for computer scientists overall.

5.2.5 Social Sciences and Humanities

Except in the primary sector, SSH workers make up the largest concentration of knowledge workers. This is especially noticeable in the service sector where, in 1991, they constitute 61 percent of the knowledge group, compared with 25 percent in the primary sector.[26] The concentrations in manufacturing and the public sector are almost equal, around 45 percent.

Growth of this category of workers is significantly lower in manufacturing, with a constant rate of 2.4 percent, than in the other three sectors for the overall period. However, this growth rate is greater than that for engineers in manufacturing and substantially higher than that for total employment.

Finally, it is interesting to note that the rate of growth of these specialists is one of the highest in the primary sector, especially during the first decade.

5.3 Data Workers' Employment

Data workers are at the heart of the information technology revolution, as their tasks are mainly designed to store and retrieve data. In the public sector, in 1991, data workers made up 50 percent of total employment while they accounted for an average 40 percent of the service sector

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[26] There was an average annual rate of growth of 7 percent for accountants between 1971 and 1991 while, in 1971, they made up 80 percent of total knowledge workers in primary industries.

between 1971 and 1991. However, it is worth emphasizing the fairly heterogeneous composition of the industries included in our service category. This heterogeneity is probably more obvious when we look at the data workers in these sub-sectors. Comparing the construction industry with FIRE shows a rather low concentration of data workers in the former and a significant one in the latter (not shown on the tables). This occupational group represents a substantially smaller proportion of total employment in the primary sector—4.5 percent in 1971 and 10 percent in 1991—and in the manufacturing sector with 23 and 21 percent respectively in 1971 and 1991. The largest concentration of these workers is therefore in the public and service sectors.

Looking at the rate of growth reveals no expansion in the manufacturing sector while the total employment rate was also close to null: a mere 0.4 percent for the entire period, it was actually negative for the second period. Only between 1971 and 1981 in medium-tech manufacturing and between 1981 and 1991 in high-tech manufacturing was there a positive rate of growth for data workers. The 4.2 percent growth rate between 1971 and 1991 in the primary sector is more impressive if we consider that the total employment growth rate was a tiny 0.3 percent for this sector overall.[27]

The rate of growth of the remaining two sectors – service and public – was 3.1 percent for the former, just above that for total employment for this sector between 1971 and 1991, and 2.2 percent for the latter, that is, just above the rate for total employment in this sector for the same period.

5.4 Service Workers' Employment

In high-, medium- and low-tech manufacturing, the rate of growth of service workers was consistently negative over the whole period. The highest growth not surprisingly, was in the service sector with 3.7 percent between 1971 and 1991. While in the public sector the rate of growth was negative in the first decade,[28] it reached 3.2 percent in the second decade. Finally, in the primary sector, this occupational group increased at a rate of 2.6 for the entire period.

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[27] This increase is largely due to three occupations, SOC-2165: Engineering Technicians, SOC-4143: Electronic Data Processing Operator and SOC-4131: Bookkeepers and Accounting Clerks – which had an average annual rate of growth of 11.1 percent, 10.6 percent and 11.8 percent respectively between 1971 and 1991.

[28] Some caution must be used here because SOC-6116: Officers, Armed Force and SOC-6117: Other Ranks, Armed Force were not included in the 1981 Census while they were included in 1971, 1986 and 1991, thus giving an artificial negative trend in 1980.

5.5 Goods Workers' Employment

In the sectors most intensive in goods workers – primary and manufacturing – negative growth on average was registered between 1971 and 1991, although there was positive growth between 1971 and 1981 in the manufacturing sector. It is worth noting that, in 1991, goods workers accounted for 73 percent of total employment in the primary sector and 61 percent of total employment in the manufacturing sector.

In contrast, in the service and public sectors, which are very low-intensive in goods workers, goods employment registered a rate of growth that was positive, though substantially less than that of total employment for the entire period.

5.6 Summary Analysis: Employment Growth in Computer-Intensive Sectors

Overall, there was a decline in demand for goods workers while knowledge workers, though still a very small proportion of total employment, constituted a growing group. We assume these trends to be associated with technological change and, in particular, computerization.

Looking at the employment intensity of industrial sectors by occupation, we see that different sectors lean more heavily toward different categories of workers. First of all, goods workers remain the most important group in manufacturing and their concentration in 1991 is still especially significant in low-tech (69 percent) and medium-tech manufacturing (63 percent); in high-tech manufacturing they represent only 41 percent. This is also the most important group in the primary sector with a substantial 73 percent of total employment.

Data workers are highly concentrated in the service sector, with a share of 40 percent, and compose 50 percent of the public sector. Finally, it is worth recalling that knowledge workers still represent only a small proportion of workers in all sectors, ranging from 10 percent for the public sector to 4 percent in the primary sector with mid-range numbers of 7 and 8 percent respectively for the manufacturing and service sectors.

6. Methodology and Variables Used

From the analysis of the evolution in employment structure reported in Section 5, we observed two important trends. The first is a tremendous employment shift from manufacturing to service sector: the Canadian economy is thus following the general pattern as advanced economies move towards service-oriented industrial activities. The second important finding is a shift towards high-skilled workers – especially knowledge and management workers – and away from goods workers. These findings and those of a previous study (Lavoie, Roy: 1998), according to which the employment shift would be mainly explained by a predominant substitution effect, prompted us to examine the role of technological change in these transformations. Obviously, as mentioned earlier, technological change cannot be reduced to computer technology; technology encompasses much more than computerization. However, the simultaneity of this shift with the increased pervasiveness and considerable performance enhancement of the computer over a period of a few years justifies a closer look.

6.1 Methodology

In this paper, we analyze the effects of technological change on the skill structure. More precisely, we attempt to correlate the diffusion of computers at the industry level with the employment shares of different categories of workers between 1971 and 1991. In the literature, there are many variants of this structure.[29] The most common are employment share and cost share. We use the former because, as Chennels and Van Reenen state, "although less appropriate from a theoretical point of view, this clearly has the advantage that it allows a statistical decomposition of the effects of technology into a relative wage component and a relative employment component" (Chennells, Van Reenen: 1998). The econometric specification used in this paper is derived from a variable cost function.

Unlike most of those who have studied the subject, we segment total employment into 9 categories of occupations in order to capture the variety of relationships between occupational categories and use of the computer. This occupational taxonomy is founded on the tasks accomplished by these workers, that is, activities related to the production and use of data as well

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[29] See Chennells and Van Reenen (1998) for an exhaustive review of the studies using the same structure and the variants.

as those related to production and maintenance of goods (Osberg: 1989).[30] In taking this approach, we assumed that the knowledge and tasks involved in various occupations were too disparate for workers to be divided roughly into two groups, that is, skilled vs. unskilled. Another major distinction of our study as compared with Berman, Bound, Griliches (1993), among others, is that we do not focus exclusively on the manufacturing sector but look at the primary, manufacturing and service sectors although, as explained above, we did exclude the public sector.

We use a translog cost function with five variable factors – wages of knowledge, management, data, service and goods workers – and a quasi-fixed factor – capital stock.

$$\begin{aligned}(1)\quad & \ln CV=\alpha_0+\Sigma_i\alpha_i\ln W_i+\tfrac{1}{2}\left[\Sigma_i\Sigma_j\gamma_{ij}\ln W_i\ln W_j\right]+\alpha_Y\ln Y+\alpha_K\ln K+\tfrac{1}{2}\left[\gamma_{YY}(\ln Y)^2+\gamma_{KK}(\ln K)^2\right]\\ & +\Sigma_i\gamma_{iY}\ln W_i\ln Y+\Sigma_i\gamma_{iK}\ln W_i\ln K+\gamma_{YK}\ln Y\ln K\end{aligned}$$

Subscript $i= k, n, m, d, s, g$ refers to knowledge, management, data, service and goods occupations. $Ln\ CV$ is the log of variable costs and $Ln\ W_i$ is the log of the wage of the ith occupation. The terms $ln\ K$ and $ln\ Y$ are, respectively, the logs of capital stock and value added.

Using Shephard's lemma allows us to derive, from equation (1), the share of occupational employment. We assume symmetry ($\gamma_{ij} = \gamma_{ji}$) and homogeneity of degree one in price.

$$\frac{\partial \ln CV}{\partial \ln Wi} = \frac{E_i(W_i, CV) * W_i}{CV} = P_i$$

$E_i(W_i, CV)$ represents the employment in occupation i (in a cost-minimizing situation) while P_i represents occupation i's share of the total wage bill.

Therefore,

$$(2)\qquad P_i = \alpha_i + \gamma_{ii}\ln W_i + \Sigma_j\gamma_{ij}\ln W_j + \gamma_{iK}\ln K + \gamma_{iY}\ln Y + e_i, \quad i \neq j$$

Using appropriate approximations,[31] the wage bill equation (2) can be rewritten in terms of employment shares (3):

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[30] See Lavoie, Roy (1998) for an explanation of the rationale behind the construction of the occupational classification used in the present study. Suffice it to say for now that it is rooted in Wolff and Baumol's categories of workers but departs from this approach quite substantially in that the sub-categorization of the knowledge group is finer.

[31] See Klein (1953) for formal demonstration.

(3) $S_i = (E_i / E_t) = \delta_i + \rho_{ii} \ln W_i + \Sigma_j \rho_{ij} \ln W_j + \beta_{iK} \ln K + \beta_{iY} \ln Y + \mu_i, \quad i \neq j$

where S_i is the employment share of occupation i. E_i and E_t are respectively the employment of the ith occupation and total employment.

Since $\Sigma_i S_i = 1$ and $\Sigma_i u_i = 0$ (covariance matrix is singular) we (re)parameterize the equation by substituting the price constraint ($\Sigma \rho_{ij} = 0$) back into equation (3) in order to make it operational.

(4) $$S_i = \delta_i + \rho_{ii} \ln\left[\frac{W_i}{W_z}\right] + \Sigma_j \rho_{ij} \ln\left[\frac{W_j}{W_z}\right] + \beta_{iK} \ln K + \beta_{iY} \ln Y + u_i,\ i \neq j$$

where W_z appears as a result of the new parametrization and represents the wage of the omitted category.

Computer investment intensity variable (C/I) is added and if we accept the homogeneity restriction of the production structure ($\gamma_{iY} + \gamma_{iK} = 0$) we can write:

(5) $$S_i = \delta_i + \rho_{ii} \ln\left[\frac{W_i}{W_z}\right] + \Sigma_j \rho_{ij} \ln\left[\frac{W_j}{W_z}\right] + \beta_{iT} \ln(C/I) + \beta_{iK} \ln(K/Y) + u_i$$

Dropping the service occupation equation and using n as the industry index, we end up with the following system of equations:

Management workers

(5.a) $$S_{m_n} = \delta_m + \rho_{mm} \ln\left[\frac{W_{m_n}}{W_{s_n}}\right] + \Sigma_j \rho_{mj} \ln\left[\frac{W_{j_n}}{W_{s_n}}\right] + \beta_{m\,tech} \ln(C/I)_n + \beta_{mK} \ln(K_n/Y_n) + u_{m_n}$$

Knowledge workers

(5.b) $$S_{kn_n} = \delta_{kn} + \rho_{knkn} \ln\left[\frac{W_{kn_n}}{W_{s_n}}\right] + \Sigma_j \rho_{knj} \ln\left[\frac{W_{j_n}}{W_{s_n}}\right] + \beta_{kn\,tech} \ln(C/I)_n + \beta_{knK} \ln(K_n/Y_n) + u_{kn_n}$$

Data workers

(5.c) $$S_{d_n} = \delta_d + \rho_{dd} \ln\left[\frac{W_{d_n}}{W_{s_n}}\right] + \Sigma_j \rho_{dj} \ln\left[\frac{W_{j_n}}{W_{s_n}}\right] + \beta_{d\,tech} \ln(C/I)_n + \beta_{dK} \ln(K_n/Y_n) + u_{d_n}$$

Goods workers

(5.d) $$S_{g_n} = \delta_g + \rho_{gg} \ln\left[\frac{W_{g_n}}{W_{s_n}}\right] + \Sigma_j \rho_{gj} \ln\left[\frac{W_{j_n}}{W_{s_n}}\right] + \beta_{g\,tech} \ln(C/I)_n + \beta_{gK} \ln(K_n/Y_n) + u_{g_n}$$

A positive coefficient on β_{itech} denotes a complementarity or labour-using technological change while a negative coefficient indicates a substitution or labour-saving technological change. The same conclusions can be drawn on the complementarity-substitution pattern of capital relative to employment form coefficient β_{ik}. Finally, the same is true of coefficients ρ_{ii} and ρ_{ij} on relative wage intensity.

As we have four periods – 1971, 1981, 1986 and 1991 – data are pooled. In these equations, industrial sector dummies and time dummies are added. Industry dummies control for fixed effects and time dummies control for institutional change or other non-specified change.

6.2 Data and Construction of Variables

Data used in this paper are drawn from many sources and are worth explaining at this stage.

6.2.1 Employment Variable

As mentioned above in the discussion of the methodology, dependent variables are employment shares of 5 broad categories of occupations and 4 sub-categories—knowledge (science, engineering, computer science, social sciences and humanities), management, data, service and goods – and are measured as the share of employment of a given type of occupation out of total employment by industry.

The occupational structure of industrial employment is drawn from four censuses –1971, 1981, 1986 and 1991. From one census to another, occupational and industrial classifications were not comparable and required some reconciliation work.[32] For each census, we have aggregated 499 occupations into 9 categories and sub-categories and the 67 industries into 30 industries.[33]

6.2.2 Relative Wages

While authors of several studies, following Berman, Bound, Griliches (1993), took for granted the non-variation of relative wages across industries, we adopted a different tack and included

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[32] The four censuses did not use the same occupational and industrial classifications. The 1971 census was coded using OCM-1970 and SIC-1970 while the 1981 census used SOC-1980 and OCM-1970. Both the 1986 and 1991 censuses were coded using SOC-1980 and SIC-1980. Adjustments were made to standardize all matrices in SOC-1980 and SIC-1980. We ended up with the same 499 occupations and 67 industries for each census. We refer the reader to Lavoie, Roy (1998) for detailed explanations.

[33] See Appendix for more details on the composition of our industrial categories.

relative wages in the model. Wage data are drawn from the 1971, 1981, 1986 and 1991 censuses and represent the average annual income earnings for full-time/full-year workers. This also includes wages and salaries of self-employed people who worked more than 30 hours per week for more than 49 weeks.

Relative wages are those of the knowledge (disaggregated into science, engineering, computer science and social sciences and humanities sub-categories), management, data and goods occupations relative to the wages of the service occupations. Since the service category is regarded as relatively exogenous in terms of technological change (due to the highly tacit nature of these occupations), it is a relatively good benchmark for other occupations.

6.2.3 Capital Stock Intensity

As explained above, the methodology defined in the last section uses the capital stock intensity or ratio as an explanatory variable. There is a link between capital and technology, although it is not linear, given the depreciation of capital. Capital stock intensity is used as an explanatory variable to approximate the productivity of equipment and machinery. It also provides indirect information on the state of technology which proves extremely useful in an inter-industrial analysis.

The capital intensity variable was constructed as capital stock over value added. The reason for choosing value added instead of output is that it gives precise information on the true production of an industry since it removes purchases (material cost) from other industries.[34] We used end-of-year capital stock data and these variables are expressed in 1986 constant dollars for the period 1971-1991.

6.2.4 Computer Investment Intensity

One major challenge with studies linking technological change, structural change and economic growth is the ability to measure technological change (OECD: 1992, 1996, Chennels, Van Reenen: 1998). As was said above, technological change can take many forms and generate important impacts with substantial occupational, industrial and firm differences. This is due to the huge variety of sources of innovation across industrial sectors.

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[34] Value added (in constant dollars), defined as the difference between the value of output and the intermediate consumption, is drawn from Statistics Canada, Cat. 15-201 and 15-202. This value is the same as the GDP at factor

In this paper, we choose computer investment intensity as the technology variable. This does not mean that we reduce technological change to computer diffusion, but, given the pervasiveness of computer-related technologies, it is worth looking at their employment effects. There are some standard technological change indicators for measuring other facets of the innovation process. Suffice it to mention research and development (R&D), which is an input indicator: patents, an intermediary indicator; and innovations, which constitute an output indicator. All of these indicators have advantages and limitations.[35]

Ideally, stock of computer investment is what we would have liked to use but the poor reliability of computer capital stock data in Canada, prevented us from doing so. The problem mainly lies in the depreciation index, which does not really represent the true value of the computer despite the amount of work done on this lately. It is especially hard to find a fair representation of the real cost of computers over time in relation to performance.[36]

In fact, it is not the level of computer performance which is required in this study but information on the spread or diffusion of computers. In other words, we want to know what share of employment is associated with a given level of computer investment intensity regardless of computer performance in a given period (current dollars) and see how this has evolved over time. Computer investment intensity allows us to appraise, at the same time, the evolution of the ratio of computers to machinery and equipment, in other words, the increasing level of computerization.

The computer intensity variable was constructed by dividing computer investment by investment in machinery and equipment. We have to account for the fact that the computing machine

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cost. Capital stock data are drawn from Statistics Canada, which used the perpetual inventory combined with a geometric depreciation method, Cat. 13-568.

[35] This is not the place to discuss the relevance of these indicators but we refer those interested in knowing more on the limitations and possibilities of these indicators to Freeman and Soete (1997).

[36] The problem is that the price of a computer over time cannot give a good approximation of the technological potential or performance of a computer. This is due, in part, to the processor, which differs in terms of memory capacity and speed, as well as to peripheral equipment (Triplett: 1989, Cole *et al*: 1986). While the hedonic index can help to appraise the real cost of the computer taking into account its performance and allow us to compare investment in the 1970s with that of the 1990s, this would not have been appropriate to our study since we did not want to measure the productivity of this equipment but to relate a level of investment to a share of employment. To better understand the complex problem of computer deflation and depreciation resulting from the significant increases in the quality of computer hardware combined with the dramatic drop in the prices of hardware mainly due to the falling cost of chips, please refer to Triplett (1989), Cole *et al* (1986), Jorgenson, Stiroh (1995) and Miller (1992).

referred in 1971 is completely different from the computer referred to in 1991. We used input-output commodities 346 (1971-1986) and 359 (1986-1991) which include the computer *per se*, that is, the hardware plus some software component. A strict delimitation of the different types of software included in our data is rather difficult to establish precisely. However, it would be quite fair to say that "marketed software products" embedded in computer equipment are included and that "custom designed software" is excluded. From 1971 to 1981, computer investment was not surveyed in the input-output tables and approximations of this investment were derived from American imports since almost all computer equipment was imported.[37]

Since we get data on employment (the dependent variable) and wages for census years only, average computer investment and machinery and equipment investment variables were constructed using "t-1" and "t+1" years around the census year "t" for 1971, 1981, 1986 and 1991. In this way, we can somewhat avoid the problem related to the volatility of investment.[38] Moreover, as computer life expectancy is approximately four years, the capital stock problem is less important here than it would be for another commodity.

Finally, it is also worth mentioning that, contrary to the American industrial system which comprises numerous firms, Canadian industries are made up of far fewer firms; this could induce more volatility over time if a large integrated firm disappeared.

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[37] Data on computer investment and machinery and equipment investment come from Statistics Canada: the former from the Input-Output Division and the latter from Cat. 61-205.

[38] Since the series of computer investment data begins in 1971, as an exception, average computer investment was calculated on the basis of 2 years, that is, 1971 and 1972.

7. The Dynamics of Wages and the Employment Structure in a Context of Technological Change

In the previous section, we sketched out the methodology and described the data used in this paper. In the following sections, empirical results are described and analyzed. The section is, in fact, composed of three parts corresponding to the analysis of the three independent variables included in our model – relative wages, capital intensity and computer investment intensity.

Three sets of regressions are reported and analyzed.[39] Under the first regression, we estimate the effect of computer investment intensity for the whole economy disaggregated over time (1971, 1981 and 1986, 1991) and that of capital intensity. The second regression disaggregates employment effects of computer intensity over time and capital intensity into three broad industrial sectors – primary, manufacturing and service. The final regression goes a little further in the manufacturing disaggregation by breaking it down into low-, medium- and high-tech manufacturing over time. Note that the effect of capital intensity is not disaggregated by year since it was quite stable over time.

After this section, the public sector is excluded from our analysis for two main reasons: the first is that the computer investment variable for this sector is an industrial average and therefore constitutes a single observation for all areas included in the public sector; the second reason is related to the fact that we constructed our capital intensity variable over value added which is a different measure for public and private sectors (see footnote 18). This is exasperating since for knowledge workers in general and some knowledge sub-categories in particular the public sector constitutes the most natural niche and, therefore, we lose some important information.

Theoretically, employment growth and wage level are related. The model of an economy in which wages are determined by a more or less flexible market is quite standard. However, the main problem in adjustment may not be price rigidities. (Freeman: 1992, 186). While wages contribute to an adjustment especially, as in our case, in response to a technological shock, we should not minimize the problems of adjusting skills of the labour force and capital stock to the

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[39] Since we detected heteroscedasticity in a multiplicative form, we weighted equations by the square root of the estimated variance of the disturbance term. To get this estimated variance, we regressed the square value of the residuals on the independent variables to which we added the industry share in the whole economy.

Table 2a
Employment Effects of Computerization: Knowledge and Management

	KNOWLEDGE						MANAGEMENT					
	(1)		(2)		(3)		(1)		(2)		(3)	
	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err
Time dummies	YES		YES		YES		YES		YES		YES	
Industry dummies	YES		YES		YES		YES		YES		YES	
Log(K/VA)	1.5061 **	(0.31)			0.7993 **	(0.25)	0.2412	(0.15)			0.0013	(0.15)
Log(K/VA)*Pri			1.9830 **	(0.95)					1.9581 **	(0.70)		
Log(K/VA)*Man			-0.2485	(0.33)					0.1090	(0.20)		
Log(K/VA)*Ser			1.4974 **	(0.35)					-0.1595	(0.17)		
Log(Wk/Ws)	-0.7400	(0.81)	0.7207	(1.77)	-0.9028	(1.74)						
Log(Wm/Ws)	0.9688	(0.81)	-1.1380	(0.77)	-0.2128	(0.75)	-1.0911 **	(0.42)	-0.6154	(0.68)	-1.2444 *	(0.64)
Log(Wd/Ws)	-7.9637 **	(1.82)	-6.4367 **	(1.83)	-3.9816 **	(1.85)	1.8198 **	(0.72)	1.7803 *	(0.97)	2.3214 **	(0.87)
Log(Wg/Ws)	7.1701 **	(1.90)	3.6980 **	(1.45)	2.2540	(1.58)	0.8820	(0.79)	0.0339	(0.92)	0.3668	(0.89)
1971 and 1981												
Log(C/I)	1.1608 **	(0.25)					0.2448 **	(0.06)				
Log(C/I)*Pri			2.7474 **	(0.52)	2.3633 **	(0.51)			-0.1484	(0.38)	-0.0982	(0.37)
Log(C/I)*Man			0.0462	(0.24)					0.1629 *	(0.09)		
Log(C/I)*LM					0.0224	(0.37)					0.0668	(0.18)
Log(C/I)*MM					1.4823 **	(0.45)					0.3745 *	(0.20)
Log(C/I)*HM					0.2650	(0.28)					0.0124	(0.08)
Log(C/I)*S			2.3832 **	(0.40)	2.2517 **	(0.42)			0.5576 **	(0.16)	0.6091 **	(0.16)
1986 and 1991												
Log(C/I)	2.5829 **	(0.43)					0.5433 **	(0.34)				
Log(C/I)*Pri			3.6924 **	(0.62)	3.3320 **	(0.63)			0.3952	(0.49)	0.5214	(0.53)
Log(C/I)*Man			1.0297 **	(0.39)					0.4546	(0.34)		
Log(C/I)*LM					0.9825 **	(0.44)					0.6031	(0.42)
Log(C/I)*MM					2.4764 **	(0.56)					0.8021	(0.50)
Log(C/I)*HM					0.8016	(0.69)					-0.6153	(0.66)
Log(C/I)*S			3.6617 **	(0.65)	3.4979 **	(0.68)			0.6251 **	(0.31)	1.4048 **	(0.67)
System weighted R square	0.9034		0.9449		0.9733		0.9034		0.9449		0.9733	
No. obs.	116		116		116		116		116		116	

Notes: Dependent variables are employment share (x100) for the Knowledge, Management, Data, and Goods occupations. Coefficients are produced by SUR estimation. Standard errors are heteroscedastic consistent. K=capital stock, VA=value added, C=computer investment, I=M&E investment, Wk= average income earnings for Knowledge, Wm= average income earnings for Management, Wd= average income earnings for Data, Wg= average income earnings for Goods, Ws= average income earnings for Service, Pri=primary sector, Man=manufacturing sector, LM=low-tech HM=high-tech manufacturing, S=service sector, * significant at the 10% level, ** significant at the 5% level.

Table 2b

Employment Effects of Computerization: Data and Goods

	DATA						GOODS					
	(1)		(2)		(3)		(1)		(2)		(3)	
	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err
Time dummies	YES		YES		YES		YES		YES		YES	
Industry dummies	YES		YES		YES		YES		YES		YES	
Log(K/VA)	3.3895 **	(0.82)			0.6118	(0.60)	-4.8594 **	(1.15)			-0.9961	(0.71)
Log(K/VA)*Pri			3.3342 *	(2.00)					-6.9138 **	(1.90)		
Log(K/VA)*Man			-0.8580	(0.76)					0.6734	(0.79)		
Log(K/VA)*Ser			2.7651	(7.81)					-4.1128	(6.78)		
Log(Wk/Ws)												
Log(Wm/Ws)												
Log(Wd/Ws)	-11.3772 **	(3.35)	-17.3753 **	(3.40)	-14.6530 **	(2.87)						
Log(Wg/Ws)	22.0652 **	(4.16)	20.0028 **	(3.05)	15.3073 **	(2.80)	-37.4635 **	(8.11)	-16.7953 **	(4.53)	-14.7764 **	(4.63)
1971 and 1981												
Log(C/I)	3.8560 **	(0.65)					-6.4636 **	(1.20)				
Log(C/I)*Pri			0.9479	(1.39)	1.0359	(1.02)			-5.8723 **	(1.40)	-5.1706 **	(1.32)
Log(C/I)*Man			1.4800 **	(0.56)					-1.1694	(0.72)		
Log(C/I)*LM					1.9754 **	(0.70)					-1.5653	(1.08)
Log(C/I)*MM					6.3424 **	(0.90)					-6.0435 **	(1.55)
Log(C/I)*HM					0.2733	(0.58)					-0.3711	(0.90)
Log(C/I)*S			7.0337 **	(3.44)	6.1133 **	(2.85)			-4.7648	(3.34)	-4.5377	(3.11)
1986 and 1991												
Log(C/I)	5.6372 **	(0.95)					-10.0250 **	(1.43)				
Log(C/I)*Pri			1.6347	(1.58)	1.4049	(1.17)			-7.5958 **	(1.66)	-6.5966 **	(1.62)
Log(C/I)*Man			2.4449 **	(0.82)					-3.1102 **	(0.90)		
Log(C/I)*LM					2.1995 **	(0.79)					-2.8332 **	(1.03)
Log(C/I)*MM					7.1580 **	(1.01)					-7.3799 **	(1.62)
Log(C/I)*HM					-0.1336	(1.33)					0.1856	(1.74)
Log(C/I)*S			8.8204 *	(4.68)	7.5398 *	(3.91)			-7.6779 *	(4.27)	-6.8249 *	(4.09)
System weighted R square	0.9034		0.9449		0.9733		0.9034		0.9449		0.9733	
No. obs.	116		116		116		116		116		116	

Notes: Dependent variables are employment share (x100) for the Knowledge, Management, Data, and Goods occupations. Coefficients are produced by SUR estimation. Standard errors are heteroscedastic consistent. K=capital stock, VA=value added, C=computer investment, I=M&E investment, Wk= average income earnings for Knowledge, Wm= average income earnings for Management, Wd= average income earnings for Data, Wg= average income earnings for Goods, Ws= average income earnings for Service, Pri=primary sector, Man=manufacturing sector, LM=low-tech HM=high-tech manufacturing, S=service sector, * significant at the 10% level, ** significant at the 5% level.

Table 2c

Employment Effects of Computerization: Science and Engineering

	SCIENCE						ENGINEERING					
	(1)		(2)		(3)		(1)		(2)		(3)	
	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err
Time dummies	YES		YES		YES		YES		YES		YES	
Industry dummies	YES		YES		YES		YES		YES		YES	
Log(K/VA)	0.2045 **	(0.08)			0.0632	(0.07)	1.1773 **	(0.17)			0.9912 **	(0.17)
Log(K/VA)*Pri			-0.7820 **	(0.25)					1.8423 **	(0.61)		
Log(K/VA)*Man			0.3505 **	(0.10)					0.8716 **	(0.25)		
Log(K/VA)*Ser			-0.0554	(0.08)					0.8916 **	(0.26)		
Log(Wsc/Ws)	1.1875	(0.78)	0.3122	(0.26)	0.3114	(0.27)						
Log(Wen/Ws)	-1.0743 **	(0.36)	-0.1297	(0.36)	0.0007	(0.39)	0.8689	(0.95)	-0.3036	(0.96)	-0.9890	(1.00)
Log(Wcp/Ws)	-0.1625	(0.12)	0.5500 **	(0.17)	0.5731 **	(0.18)	0.0911	(0.35)	-0.3106	(0.37)	-0.5706	(0.38)
Log(Wsh/Ws)	0.4663	(0.35)	0.0816	(0.29)	0.2027	(0.32)	-0.8663	(0.64)	-0.5229	(0.62)	-0.3799	(0.63)
Log(Wm/Ws)	0.1756	(0.29)	-0.7398 **	(0.30)	-0.6085 *	(0.32)	1.2461	(0.92)	1.3621	(0.95)	1.3651	(0.93)
Log(Wd/Ws)	-1.1746	(0.75)	-0.5224	(0.59)	-0.8148	(0.61)	-1.7919	(1.33)	-1.1404	(1.60)	0.1748	(1.61)
Log(Wg/Ws)	1.5847	(0.97)	0.2684	(0.51)	0.7209	(0.54)	2.0539	(1.33)	-0.0833	(1.37)	-0.5712	(1.35)
1971 and 1981												
Log(C/I)	0.1229	(0.08)					0.3781 **	(0.17)				
Log(C/I)*Pri			1.1509 **	(0.18)	1.1779 **	(0.19)			0.8532	(0.53)	0.6898	(0.49)
Log(C/I)*Man			-0.0131	(0.06)					0.0937	(0.19)		
Log(C/I)*LM					0.0232	(0.12)					-0.1781	(0.33)
Log(C/I)*MM					-0.0378	(0.11)					0.8077 **	(0.32)
Log(C/I)*HM					-0.1946 **	(0.07)					0.0130	(0.21)
Log(C/I)*S			0.1340	(0.10)	0.1561	(0.11)			-0.1071	(0.33)	-0.2957	(0.33)
1986 and 1991												
Log(C/I)	0.2033	(0.19)					0.9673 **	(0.22)				
Log(C/I)*Pri			1.2194 **	(0.21)	1.1241 **	(0.22)			1.2312 **	(0.61)	1.0962 *	(0.58)
Log(C/I)*Man			0.1603	(0.11)					0.7648 **	(0.26)		
Log(C/I)*LM					0.0754	(0.14)					0.4344	(0.30)
Log(C/I)*MM					0.0220	(0.15)					1.3138 **	(0.34)
Log(C/I)*HM					-0.3623 *	(0.19)					0.9064 *	(0.46)
Log(C/I)*S			0.3765 **	(0.19)	0.2255	(0.21)			0.8708 *	(0.50)	0.5718	(0.52)
System weighted R square	0.7843		0.8815		0.9099		0.7843		0.8815		0.9099	
No. obs.	116		116		116		116		116		116	

Notes: Dependent variables are employment share (x100) for the Science, Engineering, Computer Science, and SSHs occupations. Coefficients are produced by SUR estimation. Standard errors are heteroscedastic consistent K=capital stock, VA=value added, C=computer investment, I=M&E investment, Wsc= average income earnings for Sciences, Wen= average income earnings for Engineering, Wcp= average income earnings for Computer Sc., Wsh= average income earnings for SSHs, Ws= average income earnings for Service, Pri=primary sector, Man=manufacturing sector, LM=low-tech manufacturing, MM=medium-tech manufacturing, HM=high-tech manufacturing, S=service sector, * significant at the 10% level, ** significant at the 5% level.

Table 2d

Employment Effects of Computerization: Computer Science and Social Sciences and Humanities

	COMPUTER SCIENCE						SOCIAL SCIENCES AND HUMANITIES					
	(1)		(2)		(3)		(1)		(2)		(3)	
	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err	Coeff	Std-Err
Time dummies	YES		YES		YES		YES		YES		YES	
Industry dummies	YES		YES		YES		YES		YES		YES	
Log(K/VA)	0.3409 **	(0.06)			0.1875 **	(0.06)	-0.0235	(0.25)			-0.6475 **	(0.25)
Log(K/VA)*Pri			0.4244 **	(0.18)					0.6609	(0.64)		
Log(K/VA)*Man			0.0966	(0.08)					-1.2374 **	(0.30)		
Log(K/VA)*Ser			0.2414 **	(0.08)					-0.2317	(0.47)		
Log(Wsc/Ws)												
Log(Wen/Ws)												
Log(Wcp/Ws)	0.1364	(0.17)	-0.1967	(0.29)	-0.1856	(0.31)						
Log(Wsh/Ws)	-0.2631	(0.28)	-0.0371	(0.26)	-0.0579	(0.27)	1.9425	(1.25)	1.4954	(1.08)	0.7777	(1.09)
Log(Wm/Ws)	-0.0672	(0.25)	0.4559 *	(0.26)	0.4166	(0.26)	-2.0250	(1.28)	-3.5609 **	(1.32)	-3.4760 **	(1.37)
Log(Wd/Ws)	-0.4295	(0.43)	-0.9670 *	(0.55)	-0.5185	(0.56)	-1.2984	(1.80)	-2.5197	(2.19)	-1.2545	(2.17)
Log(Wg/Ws)	0.3167	(0.40)	-0.2373	(0.43)	-0.4263	(0.43)	2.3654	(1.97)	3.2172	(1.95)	2.4938	(2.03)
1971 and 1981												
Log(C/I)	0.1480 **	(0.04)					0.0116	(0.12)				
Log(C/I)*Pri			0.1256	(0.14)	0.1206	(0.14)			1.2722 **	(0.54)	0.9675 *	(0.53)
Log(C/I)*Man			0.0381	(0.05)					0.0266	(0.12)		
Log(C/I)*LM					-0.0616	(0.10)					-0.2553	(0.49)
Log(C/I)*MM					0.0931	(0.10)					-0.0217	(0.49)
Log(C/I)*HM					0.1042 *	(0.06)					0.1615	(0.13)
Log(C/I)*S			0.1594 *	(0.09)	0.1345	(0.09)			1.6447 **	(0.67)	2.1159 **	(0.74)
1986 and 1991												
Log(C/I)	0.4126 **	(0.09)					1.2643 **	(0.34)				
Log(C/I)*Pri			0.3479 **	(0.17)	0.3923 **	(0.17)			1.5437 **	(0.65)	1.5362 **	(0.65)
Log(C/I)*Man			0.3519 **	(0.09)					0.1466	(0.37)		
Log(C/I)*LM					0.2910 **	(0.11)					0.3264	(0.50)
Log(C/I)*MM					0.4731 **	(0.12)					0.4159	(0.57)
Log(C/I)*HM					0.5216 **	(0.15)					0.5808	(0.72)
Log(C/I)*S			0.5344 **	(0.16)	0.5690 **	(0.16)			1.5699 *	(0.82)	2.6802 **	(1.03)
System weighted R square	0.7843		0.8815		0.9099		0.7843		0.8815		0.9099	
No. obs.	116		116		116		116		116		116	

Notes: Dependent variables are employment share (x100) for the Science, Engineering, Computer Science, and SSHs occupations. Coefficients are produced by SUR estimation. Standard errors are heteroscedastic consistent K=capital stock, VA=value added, C=computer investment, I=M&E investment, Wsc= average income earnings for Sciences, Wen= average income earnings for Engineering, Wcp= average income earnings for Computer Sc., Wsh= average income earnings for SSHs, Ws= average income earnings for Service, Pri=primary sector, Man=manufacturing sector, LM=low-tech manufacturing, MM=medium-tech manufacturing, HM=high-tech manufacturing, S=service sector, * significant at the 10% level, ** significant at the 5% level.

adoption of new technologies (Freeman: 1992, 186). For example, if a category of labour becomes scarce following or even before the adoption of new technologies, we should expect that employers will compete for these high-demand workers and, consequently, an upward pressure on wages will occur. The reverse should also be true: in a context of high unemployment of the same high-skilled workers, for example, the pressure on wages will be downward. In this section, we will show, on the basis of our findings, the role of the wage employment nexus in relation to technological change.

In general, we can see that the inclusion of relative wages in the model does not show any fundamental change in the relationship between a category of workers and computer investment intensity.[40, 41]

Although it is worth examining the role of relative wages in some occupations, the analysis is complex given the number of categories of occupations involved in the present study as compared with other studies, which generally deal with, at most, two categories, that is, skilled vs. unskilled. The first observation of interest concerns the fact that for all categories of occupations (data, management, goods), when there is a relative increase in their wages, we find a decrease in their employment share; the only exception is the knowledge workers category, where the effect of wages is not significant. More work should be done to understand what differentiates knowledge workers' wage adjustment mechanism from that for other categories of workers.

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[40] We also performed regressions without relative wages (not shown here). The magnitude and trends of the computer investment coefficients remained the same.

[41] A simultaneity bias could be suspected in our "relative wages" variable. In order to test the assumption of endogeneity of this variable, an "omitted variables" Hausman test has been used. This "instrumental variables technique" requires appropriate instrumental variables that are difficult to find. However, we chose two series of alternative wages as instrumental variables and, on this basis, rejected the assumption of endogeneity of the relative wages variable. The chosen alternative wages are those of the following occupations: *Accountants, Auditors and Other Financial Officers* (SOC-1171) and *Architects, Engineers and Community Planners* (SOC-214/215) for the Knowledge category, *Production Management* (SOC-1143) and *Other Managers and Administrators* (SOC-113/114) for the Management category, *Bookkeepers and Accounting Clerks* (SOC-4131) and *Stenographic and Typing* (SOC-411) for the Data category, *Guards and Related Security* (SOC-6115) and *Other Service* (SOC-619) for the Service category and, finally, *Industrial, Farm and Construction Machinery Mechanics and Repairers* (SOC-8584) and *Material Handling and Related Occupations* (SOC-931) for the Goods category.

There are some other findings worth mentioning if we look more specifically at the effect of relative wages on the employment shares of different categories of workers. However, it would require careful handling since this is not a direct cause-and-effect relationship. The first point regards the role of relative data wages in the share of knowledge workers. We find that when there is an increase of 1 percent in relative data wages, we see a decrease in the share of knowledge workers.[42] It is also interesting to observe that when there is an increase of 1 percent in relative goods wages, the picture is reversed for knowledge and data workers' employment shares. Finally, an increase in the relative wages of data workers is also associated with an increase in the share of management workers.

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[42] The analysis of the effect of relative wages on the employment structure, such as done in this section, does not imply a causality link between the relative wages of one category of workers and the share of another category of workers. The situation pictured can be due to a multitude of other variables and does not simply involve a substitutive relationship between one category of workers and another.

8. Capital/ Skill Complementarity

We also assume that capital intensity will be complementary to certain skills and could therefore explain part of the employment composition shift. Across sectors, the capital intensity measure provides additional information on the role of the computer and controls for some technology characteristics of production (Colecchia, Papaconstantinou: 1996). Indeed, it is useful to delineate inter-industrial differences in terms of production processes.

8.1 A Pattern of Inter-Occupational and Cross-Sectoral Capital Intensity Over Time

First of all, it would be interesting to better understand the dynamics between capital intensity, measured by capital over value added (K/VA), and technology at the sectoral level. The question we ask here is: Does the relative utilization of knowledge, management and data workers increase with capital intensity and does the relative utilization of goods workers decrease? That is: Is increasing physical capital intensity complementary to human capital (i.e. high-skilled workers)?

With reference to Tables 2a, b, c and d under estimate 1, shows that for all occupational groups, the association with physical capital over time is stable (though not reported in these tables), unlike the case with computer intensity, which differs from a given year to another. Moreover, regardless of the industrial disaggregation, it is with the data group of occupations that the complementarity of capital is the strongest, followed by the knowledge group. There is no association between management workers and physical capital and, therefore, the rapid increase of these workers cannot be related to physical capital. It is also interesting, though not surprising, to observe the strong substitutive relationship between goods workers and capital.[43]

Disaggregating knowledge occupations into four groups – science (pure and applied combined), engineering, computer science and social sciences and humanities – we note some differences in capital/skill complementarity as well as in the magnitude of this relationship. First, there is no complementarity for social sciences and humanities. Second, for all other sub-groups, there is a

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[43] As capital includes old as well as new equipment, computerized equipment would necessarily be included in the numerator of the capital intensity variable.

significant relationship with capital though the level varies. The strongest complementarity is with engineering, followed by computer science and then science.

A glance at cross-industry comparisons, under estimate 2, reveals different relationships between categories of workers and capital. For example, we can see that the substitutive relationship between goods workers and capital is present in the primary sector but, quite surprisingly, not in the manufacturing sector. We also observe a strong complementarity for management workers in the primary sector. When our results are disaggregated across industries, the high complementarity found between data workers and capital in the economy as a whole is no longer significant for manufacturing and service but, at around 10 percent, remains significant in the primary sector. Finally, knowledge workers and capital remain complementary in primary industries as well as in service industries.

If we examine knowledge sub-categories by industrial sector, it is in the manufacturing sector that we find a complementarity with capital intensity for science whereas in the primary sector the relationship is a substitutive one. In the service sector, there is a complementarity for computer science and this is even more pronounced for engineering workers. Indeed we see the strong complementarity between engineers and physical capital for all industrial sectors. Finally, it is especially interesting to note that there is no association between capital and social sciences and humanities in the primary and service sectors while there is a substitutive association in the manufacturing sector.

8.2 A Satisfactory Explanation for the Upward Shift in Employment

Can we attribute the observed upward shift towards knowledge, management and, to a lesser extent, data, as described in Section 4, to increasing capital intensity? At first glance, since the latter did not rise appreciably over the 1971-1991 period, this would seem an unlikely explanation for such an important shift (Wood: 1994, 80, Goldin, Katz: 1998, 709). In fact, the interesting point to make here is that while the effect of capital intensity was no different from that of computer intensity in 1971 and 1981, the relationship with computer intensity was the stronger of the two for 1986 and 1991. Therefore, in these later years, we can clearly observe a more dominant computer effect than in 1971 and 1981. The evolution of the impact of computers will be examined in further detail in the following section.

Including a capital intensity variable in our model allowed us to give a more precise estimate of the relationship between computer intensity and skill categories by industrial sector. We now turn to the key results of the model, that is, the impact of computer investment on employment structure.

9. An Overview of Computer Investment Trends

There has been widespread diffusion of computers in households and the business world since the beginning of the 1970s.[44] As mentioned above, the development of computer-related technologies, combined with a price reduction allowed this tremendous spread of computerization. However, the role of the computer is extremely versatile across occupations and its impact differs considerably from one industry to another.

To better understand the dynamics of the role of the computer in a job, we must first understand the configuration of the job, the architecture of its tasks. A job is fundamentally composed of two types of activities, core and complementary. A second characterization can be made in terms of degree of tacitness and codification. The combination of these job features – tacit vs. codified, and core vs. complementary – makes the impact of one computer quite different from a job to another, depending on how the job embodies these features. The impact can range from a complete substitution for a job if the core activity is completely routinized and therefore codifiable – this may be what has happened to the clerk typist occupation in the data category – to no impact whatsoever if both core and complementary tasks are fully tacit. We can see a good example of this in the case of workers in our service category of occupations: we could hardly see a computer doing the work of a hairdresser.[45] This does not mean that substitution will always be impossible since there is a spiral evolution between tacit and codified tasks, but before a computer can even support the tasks of the hairdresser, it might take some time. Between these two extremes, there is a spectrum of possibilities, depending on the intensity of these features in the occupation.

For example, a computer can reduce the complexity of calculations a scientist has to do as a complementary activity as well as speed up these calculations; this results in a new level of complexity of the core activities moving the search process forward, so that the judgment skills essential to the core activities to analyze and interpret the results of these complex calculations

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[44] Microcomputers were included in computer investment data from 1982 (Miller: 1992, 95).

[45] As stated by Autor, Katz and Krueger (1997, 14) for the American economy, which should not be so far from the Canadian reality, "computer use has become especially prevalent in such industries as legal services, dairy products, advertising and public administration, while remaining unsurprisingly relatively rare in logging, taxicab services, beauty shops, and bowling alleys."

may become even more important, thereby reducing the productivity of a scientist and thus increasing the rate of employment of this category of workers.[46] Although the role of the computer in this example is accessory, it can ultimately change the number of scientists required to do a job, given that it helps to precipitate a considerable complexity in the search process, pushing back the frontiers of knowledge.

Based on the findings of previous studies, the key assumption of the paper is that skills of highly educated workers are complementary to computer technology and should somewhat explain the significant upward shift towards these workers. Here we want to take a step further by analyzing our results in the light of the above discussion. In our occupational classification, highly skilled workers correspond to the knowledge, data and management categories of workers. We assume that these workers perform different tasks with completely different characteristics. Accordingly, we assume that the magnitude of the computer impact will differ from one category of workers to another. To investigate the complementarity and substitutive association between the computer and the tasks, we will take a comparative view between categories of occupations over time and across industries.

9.1 Complementarity and Substitution at the Aggregate Level

From Tables 2a, b, c and d under estimate (1), that is, regardless of industrial sector, it clearly appears that there is an increasing complementarity between computer intensity and the knowledge, data and management categories of workers. It is, however, with the data category of occupations that the association is the strongest over the 1971-1991 period, which comes as no surprise since, generally, their core tasks consist in storing and retrieving data. This is an interesting finding, since this group of occupations did not grow as rapidly as the knowledge category of occupations, as seen earlier in Section 5.

Between goods workers and the computer, on the other hand, there is a substitutive association and the magnitude of this relationship increased substantially over these two decades reflecting, to some extent, the importance of expert systems software which replaced the routinistic work of

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[46] The 'Tammany Bank' example of Levy and Munrane (1996) is very relevant to this dynamic. They basically distinguished two types of tasks – routine tasks and exceptions – which correspond essentially to our codifiable and tacit tasks. In the second category, they classify judgment activities that cannot be codified and thus become an important part of the tasks.

these workers.[47] According to Berman, Bound and Griliches, these computer-aided technologies "could reasonably be expected to be production labour-saving rather than production labour-using" (Berman, Bound, Griliches: 1993). Moreover, Baldwin *et al*, referring to Bylinsky, qualify these new manufacturing processes as "soft manufacturing" as opposed to traditional manufacturing. This means essentially "software and computer networks are as important as production machines" (Baldwin, Gray, Johnson: 1997).

Within knowledge sub-groups, only for the computer scientist and the engineer is there a complementary association with the computer during the first decade. During the second decade however the closest complementarity is with the SSHs, followed by engineering and computer science.

The conceptual framework developed above could be useful in interpreting our results. For example, it could help to explain the differences between the data and goods categories of workers. The core tasks of a goods worker are characterized by their codifiability which explains the high level of replacement of goods workers by the computer (in this case, it is probably the expert systems software component which is responsible). Let us compare this with the tasks of a secretary – included in the data category. While manual and secretarial workers both have codifiable core activities, the secretary has multiple-task core activities as well as tacit complementary activities (such as dealing with people and thus using judgment); manual workers, on the other hand, have, in general, specialized core tasks with minimal complementary tasks. As a result, if a secretary's core activity is replaced by a computer, the content of the job will be transformed, forcing a change in the secretary's tasks – from typing to editing, for example (since computers are widespread, people who write papers and reports now do their own typing). In other words, while the secretary was able to shift from a core activity to another and even from one core activity to a complementary activity, the narrowly specialized competencies of a goods worker may prevent him (her) from doing the same.

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[47] It is also very likely that the computer investment variable, which essentially includes computer hardware and software, is in addition highly complementary to other types of equipment and gives this pattern of association between goods workers and computer intensity.

9.2 Computer Technology/ Skill Complementarity: Inter-Occupational and Cross-Sectoral Patterns

Despite the predictions of the automation debate of the 1950s, according to which computerization would inevitably lead to mass unemployment, something more complex is happening in the current labour market in relation to the diffusion of information and communication technologies, in general, and computers, in particular. Computers and computerized equipment have, instead, eliminated occupations requiring physical effort and replaced them with occupations depending more on mental ability. This shift in the pattern of skills is also accompanied by a shift in the corporate archetype from 'producer organization' to 'thinking organization' (Kodama: 1991).

However, there are large and consistent variations across industrial sectors in both the sources and accumulation patterns for technological change.[48] This is due to the variety of technology conditions – technological opportunity and appropriability – and market conditions as well as the average firm size and the degree of concentration of industrial activities governing these sectors (Dosi, Pavitt, Soete: 1990, Dosi: 1988). This variety will likely induce significant differences in patterns of industrial employment. However, given the widespread diffusion of computing technologies, we should expect less variety than with other technologies. Finally, all sectors encompass different combinations of occupations, so there will probably be quite a different pattern of relationships between the computer and occupations across industrial sectors.

As explained above, the broad level of industrial aggregation of the computer investment variable forced us to develop a very basic industrial taxonomy. Despite the fact that the taxonomy is simple, it proved worthwhile, revealing important differences in the pattern of relationships with computer intensity.

For instance, one important fact is that the service sector is the one where knowledge and data workers are most concentrated, while management workers have quite a similar intensity across industries.[49] Disaggregating manufacturing industries into high-, medium- and low-tech brings in

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[48] For a complete analysis of the magnitude of this industrial variety, see Pavitt: 1984, Dosi, Pavitt, Soete: 1990, Dosi: 1988 and Napolitano: 1991.

[49] Once again, some caution must be given to the service category as it embodies a great deal of non-homogeneous industrial sectors.

some differences in terms of worker concentration. It is in the high-tech manufacturing sector that we find the highest intensity of management workers. Does this mean that these are the sectors where complementarity with the computer will be greatest?

In this section, we examine the evolution of the level of complementarity between computer intensity and various occupations across industrial sectors. As explained above, the nature and characteristics of the tasks accomplished by a worker are important elements to take into account in order to determine how computerization may have changed the employment structure. In other words, the less tacit and, therefore, the more codifiable the tasks, the more likely that they could be replaced by a computer. On the other hand, the more tacit these tasks, the less likely that a computer will be able to substitute for them. However, it may be that only some of the tasks are codifiable and, therefore, replaceable; in this case, with the support a computer can provide, the focus of the job may shift from core activities to complementary ones. For example, we assume that the speed of scientific and technological progress, directly affecting core science and engineering activities, has been partly related to the widespread adoption of computing technologies, allowing a rapid spread of new production processes, new research challenges and new complexity.

Moreover, whether activities are core or complementary to the job will also play an important role in the process of employment creation/destruction. In the light of the above analysis, we will do a detailed examination of occupations.

9.2.1 Knowledge Workers

The strong increase in knowledge workers over the 1971-1991 period led us to assume that a technological shock had occurred. Moreover, given the pervasive nature of the computer, which invaded all spheres of private and professional life, and considering the simultaneity of events, we also assumed that the computer *per se* might have been an important determinant in this increasing trend. However, the knowledge worker category is composed of a heterogeneous collection of workers who do not all relate to the computer in the same way. For example, the computer is the key tool of the computer scientist but is only an accessory for the scientist. It therefore becomes important to nuance the relationship from one category to another. Before doing so, let us examine how the aggregate group relates to computer intensity as a whole.

According to our findings, as shown in Tables 2a, b, c and d, there is, in general, a significant complementarity between knowledge workers and the computer for all industrial sectors from 1980 onwards; the magnitude differs slightly from one sector to another but increases over time. As early as 1971, there is a complementarity association in the primary, service and medium-tech manufacturing sectors.

It is in the primary sector that the relationship is strongest in 1971 and 1981, while in 1986 and 1991; this is outpaced by complementarity in the service sector. For these later years, low-tech manufacturing also presents a picture of complementary between knowledge workers and computer use. Overall, the findings mean that where there is a knowledge worker, there should be a computer. However, the computer *per se* could not replace the tasks of the knowledge worker *per se*; it is mainly a tool used to assist the worker in his (her) job. Furthermore, we know that there exists a huge variety of tasks across knowledge workers, and this variety might be reflected in a finer disaggregation of occupations.

Sciences

The findings are less obvious for this category than for other occupational categories. In some sense, it is quite understandable since contrary to other workers, scientists are not spread evenly across all industrial sectors. We found quite a stable complementary association over the two decades between the tasks of science workers and the computer in the primary sector while, quite surprisingly, the computer tends to maintain a substitutive association with these workers in high-tech manufacturing.

Engineering

We tend to imagine the computer as being the most powerful tool of the engineer especially with expert systems software. While the primary, manufacturing and service sectors are almost equally intensive in engineers, and increasingly so over time, it is in medium-tech manufacturing that the intensity is the greatest especially for 1986 and 1991. This is also the sector where the complementarity with the computer is strongest but not significantly different over time, suggesting that the engineering workforce move in tandem with the diffusion of the computer.

In the primary sectors and high-tech manufacturing, we also find a complementarity in 1986 and 1991. Examining the case of goods and engineering workers together in light of the diffusion of the computer, it seems that expert systems software was probably a catalyst in the substitution of engineers for goods workers.

Computer Science

The most natural relationship with the computer should be found with the computer scientist. In fact, the computer is the key reason for computer science to exist. While we find an obvious complementarity, our findings must be nuanced. There is a complementarity, but it is less strong than initially thought. How can we explain these observations? We found some interesting facts: for example, the computer is more complementary to computer scientists in sectors in which the computer is used to assist in complex tasks, such as high-tech manufacturing (for the whole period) and the service sector (in 1986 and 1991). The occupation might thus be more closely related to computerized equipment than to microcomputers. Moreover, given the increasing availability of user-friendly software as well as the development of computer assisted software engineering (CASE), which consists in methods to simplify, document and maintain software, and the development of object oriented programming languages (OOP) (Steinmueller: 1995), the need for a computer scientist is certainly less important than the need for technicians in electronics.[50] The complementarity is extensive across sectors in the second decade but, as expected, less significant across sectors in the first decade.

Social Sciences and Humanities

The SSH category is the largest sub-category of the knowledge group and comprises a variety of expertise (Lavoie, Roy: 1998). For example, the accountant occupation made up between 40 and 50 percent of the SSH category, the artistic group accounted for a little less than a third and the legal profession made up 10 percent of the category leaving about 10 and 20 percent for the remaining occupations between 1971 and 1991.

We found a complementarity with computer intensity during the first decade in the primary and service sectors and no significant difference in 1986 and 1991. This is a little surprising since these workers use mainly PCs and workstations, which became widely available towards the end of the 1970s.

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[50] It is interesting to see the rapid increase across industrial sectors of the occupation SOC-4143: Electronic Data Processing Equipment Operator included in our category 'data' which tends to support this assertion.

The strongest complementarity of these workers with the computer is in the service sector, which comes as no real surprise given the concentration of these workers. Indeed, the high concentration of this sub-group within the knowledge category might also explain the strength of the complementarity at the aggregate level in 1986 and 1991.

9.2.2 Management Workers

If there were one category of workers for which the relationship with the computer is close but not simultaneous, this would be management. One core activity of these workers is planning, including the planning of computer adoption. In other words, the volatile results related to this category of workers might be the result of a certain lag effect between the adoption of computers and the activity of planning it. We do find some degree of increasing closeness in the service sector up to 1991 along with a weak but significant 10 percent level in medium-tech manufacturing in 1971 and 1981 that disappears later in the second decade.

9.2.3 Data Workers

It appears that the strongest complementarity between computer technology and skills is among data workers in the medium-tech manufacturing sector, although the level remains steady in 1986 and 1991. The other sector with a strong complementarity is the service sector, though the level is only 10 percent in 1986 and 1991. There is also a complementarity in low-tech manufacturing for all years. As a whole, data occupations, whose core tasks consist in using data, can hardly do without a computer. Although less significant than the increase in knowledge workers, there has been an increase in these workers, leaving us to assume that no major substitution took place for this group of workers. This is confirmed in research by Hunt and Hunt, reported by Cyert and Mowery: "They argued that these flaws led the studies to overstate the job-displacing impact of technological change on clerical workers" (Cyert, Mowery: 1987, 89).

9.2.4 Service Workers

This category of workers is neither substituted nor complemented by the computer (not shown on the tables). This is not surprising since their tasks are not only uncodifiable but rarely require the use of a computer, and, if then, only for supporting complementary tasks. For example, it would be rather unusual to find a hairdresser doing his or her tasks with the support of a computer, as was explained above.

9.2.5 Goods Workers

The association between the computer and goods workers goes only in one direction, which is towards substitution, as shown by the negative coefficient of β_{tech} for most industries. The strongest and most steadily growing computer substitution relationship for goods workers is in medium-tech manufacturing followed by the primary sector. It is interesting to observe that as early as the first decade, substitution took place in the medium-tech manufacturing and primary sectors while it is only in the second decade that low-tech manufacturing experienced such a relationship, as did the service sector.

Essentially, this means that the work of goods workers has become increasingly obsolete and, furthermore, that this rate of obsolescence is similar to the rate of computer investment. In other words, the greater the investment there was in computers, the more the employment share of goods workers tended to decrease.[51] The routinized nature of core tasks accomplished by goods workers certainly explains much of the substitution. More than likely it is the CAD/CAM and CAD/CAE software portion of computer investment that has had the strongest effect.

9.3 A Summary Analysis: Sectoral Patterns

In general, we found that computer diffusion favours professional and technical (knowledge, management, and data) workers as opposed to manual (goods) workers. However, a variety of industrial patterns emerged and these differences are worth analyzing a little further.

Some sectors have been more susceptible to computerization: these are the service and to an almost equal extent, primary and medium-tech manufacturing sectors. Since this last category has been characterized by a higher intensity of technology over time, it is easy to observe a stronger reaction in the complementary association between categories of workers in this sector and computerization. Industries in the medium-tech manufacturing sector may in fact be new industries (in our classification, aircraft and parts ended up in this sector) and they may have brought about new employment opportunities, especially for knowledge workers (Freeman, Soete: 1997, 408).

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[51] Once again some caution must be exercised here since we might capture more than the computer effect using the computer intensity variable – that is, what we find here may very well be the result of the influence of advanced manufacturing technologies in general. A companion paper will address computerized equipment directly and should lead to a better understanding of the effect of the computer on goods workers.

The shift towards service industries from manufacturing has been simultaneous with the increase of knowledge workers. However, as explained by Freeman and Soete (1997), the immaterial nature of knowledge in the service sector means that codification will never be complete. Therefore, it is unlikely that a substitutive relationship will arise between knowledge workers and the computer in this sector.

> The codification process will even rarely reduce the relative importance of tacit knowledge in the form of skills, competencies and other elements of tacit knowledge, rather the contrary. It is these latter activities which will become the main value of the service activity, that is, the 'content'. While part of the latter might be based on pure tacitness, such as talent or creativity, the largest part will be greatly dependent on continuous new knowledge accumulation – learning – which will typically be based on the spiral movement whereby tacit knowledge is transformed into codified knowledge, followed by a movement back where new kinds of tacit knowledge are developed in close interaction with the new piece of codified knowledge (Freeman, Soete: 1997, 405).

10. Computer Technology – Substitute for or Complement to Workers: Some Conclusions

There is increasing empirical evidence of a shift from unskilled workers towards skilled workers in Canada and elsewhere (Berman, Bound, Griliches: 1993, Lavoie, Roy: 1998, Osberg, Wolff, Baumol: 1989). While many factors are probably responsible for the trend, technology has been singled out as the main determinant. This paper has provided an analysis of the employment effects of computerization across industrial sectors. In presenting these results, we have attempted to go beyond simple description and offer explanations for the various impacts the computer has had on diverse categories of workers and industries. We developed an analytical framework that proved very useful for understanding occupational diversity in relation to computerization. We assumed that the association of workers with the computer is defined by the nature of the knowledge – tacit vs. codified – required by an occupation and the inherent character of the tasks – core vs. complementary – related to this occupation.

The major findings include the following:

i) In general, the association between workers and physical capital is not significantly different from their relationship with the computer in the first decade, but the impact of computers outweighed the effect of capital in 1986 and 1991. This clearly reflects the significant diffusion of computers from the mid-1980s onwards.

ii) There are some important differences across industrial sectors in the computer intensity level as well as in the skill composition, leading to differences in the cross-sectoral impacts of computerization on different occupational categories. It is in the service industries that the computer effect is the strongest and most pervasive across occupations, followed by medium-tech manufacturing.

iii) A complementarity between computers and the data and knowledge categories of workers is established in this paper. While for the knowledge category the use of a computer is mainly a complementary activity (supporting the core activities), except perhaps for computer scientists, it more frequently constitutes a core activity for data workers who are forced to redefine the content of their jobs on the basis of their largely tacit complementary activities. As a result, there is a shift from codifiable core tasks to tacit complementary tasks.

iv) Given the strongly tacit nature of the service category of workers, we find no association with the computer, meaning that computer use is essentially non-existent for this category of workers given the nature of their core and complementary activities.

v) The category of goods workers has a strong substitutive relationship with the computer especially in the medium-tech manufacturing and primary sectors. This effect is most certainly related to expert systems software included in the computer investment data.

vi) As a whole, however, computerization does not appear to be a labour-saving process but rather a labour-using one, which partly explains the shift in the composition of labour over the last two decades. This confirms the findings of other studies.

These findings raise additional questions as to the role of computerization in the general shift from a manufacturing to a service-related base economy. For example, to what extent is the role of computerization in the declining relative demand for goods workers independent of an increase in the relative demand for knowledge workers? As Wood state, "it would be absurd to suggest that trade with the South precipitated the invention or diffusion of microprocessors, but it seems rather likely that competition from the South influenced the ways in which microprocessors were introduced into production processes" (Wood: 1994, 279). It would be interesting, then, to assess whether the degree of international competition intensity across industries partly explains the skill upgrading, since, as emphasized by Berman, Bound and Griliches, "the uniqueness of the computer revolution" should not be exaggerated (Berman, Bound, Griliches: 1993).

Another question is related to the direction of the causality link between high-skilled workers and adoption of technology. The most likely interpretation would be that new technologies will be adopted once some high-skilled workers are in place – with high-skill workers encouraging the adoption of technological change and vice versa (technological change requiring the skills of these workers). This starts a virtuous circle, as more technological change takes place and more high-skilled workers are hired to deal with the new equipment. This is of course only one interpretation and we think that the direction of the relationship depends on the industrial sector and the nature of the technology being adopted.

We found a complementarity between knowledge and data workers and the computer but is it enough to affect skill demand? We believe that the computer investment variable captures the general technology trend and that other technology variables would be required to capture all technology effects and even purify the computerization one. This is what we intend to do in the next studies by using advanced manufacturing technologies and other technology variables.

Finally, although a useful exercise, looking at the impact of computerization on the employment structure is like looking at the tip of an iceberg. Electronics and microelectronics have given impetus to the development of new and powerful technological trajectories – neural networks and fuzzy technology, among others – which will eventually have a much greater impact than any effect computerization may have. Compared with what we have seen so far, the impact on the employment structure may be extreme, since the complexity brought in by the computer will be reduced through advances in artificial intelligence, and so on. In other words, the computer has been very successful in replacing codifiable knowledge but quite inadequate in replacing tacit knowledge. The new generations of technology, created through the fusion of electronics, biology and other technologies, will quite probably directly target the replacement of tacit knowledge which, up to now, has been fundamentally a human preserve. Therefore, the employment effects resulting from computerization as documented in this paper are only a taste of what we might expect in the future.

Appendix

Descriptive Statistics by Industry, 1971 and 1991

INDUSTRY	YEAR	Kn (%)	Mg (%)	Dt (%)	Sv (%)	Gd (%)	C/I (x100)	C (M$)	I (M$)	K/VA	Wk/Ws	Wm/Ws	Wd/Ws	Wg/Ws	EMPLOY (%)
PRIMARY															
Agricul. & Fishing	1971	0.20	3.86	1.39	0.54	94.01	0.10	0.76	758.17	1.55	2.46	1.22	1.39	0.82	6.59
	1991	0.95	14.08	6.81	1.52	76.63	0.65	11.78	1824.40	1.02	1.82	1.49	1.38	1.15	4.11
Logging & Forestry	1971	2.48	0.70	6.59	3.14	87.09	1.19	0.62	51.87	0.66	1.63	4.21	1.08	1.14	0.83
	1991	7.71	3.43	11.41	3.17	74.28	2.50	1.79	71.73	0.24	1.54	2.11	1.14	0.83	0.61
Mining & Oil Wells	1971	8.37	1.85	15.53	2.34	71.91	2.92	12.54	429.13	1.09	2.23	4.81	1.38	1.41	1.73
	1991	12.72	7.53	18.27	1.76	59.72	1.82	16.16	876.50	1.63	1.68	2.34	1.11	1.33	1.34
TOTAL	**1971**	**1.95**	**3.19**	**4.54**	**1.12**	**89.20**	**1.12**	**13.92**	**1239.17**	**1.21**	**2.17**	**1.36**	**1.33**	**1.13**	**9.15**
	1991	**4.24**	**11.56**	**9.81**	**1.74**	**72.65**	**1.08**	**29.73**	**2772.63**	**1.32**	**1.99**	**1.36**	**1.22**	**1.00**	**6.06**
MANUFACTURING															
LOW-TECH															
Food & Beverage	1971	2.03	1.57	24.69	3.15	68.56	4.30	9.96	231.40	0.39	1.63	3.22	1.18	1.06	3.00
	1991	2.82	8.31	20.69	3.38	64.80	5.75	76.21	1325.50	0.46	1.61	2.05	1.15	1.10	1.88
Tobacco	1971	2.93	2.02	25.52	4.38	65.14	14.90	1.46	9.77	0.20	1.68	3.13	0.98	0.97	0.11
	1991	4.85	14.78	24.67	3.29	52.41	6.58	2.72	41.30	0.26	1.37	2.01	1.14	1.26	0.03
Leather	1971	1.44	1.85	14.86	1.31	80.54	8.99	0.44	4.90	0.23	1.82	3.59	1.40	0.98	0.33
	1991	1.93	8.52	14.57	1.29	73.69	16.26	1.65	10.17	0.31	1.99	2.52	1.85	1.30	0.12
Textile	1971	2.77	1.99	17.22	2.66	75.35	1.92	1.41	73.33	0.75	2.03	4.63	1.46	1.08	0.97
	1991	3.62	9.23	17.62	1.24	68.30	2.14	5.22	243.63	0.41	1.20	1.65	0.88	0.78	0.37
Clothing	1971	1.87	1.87	15.05	5.47	75.74	6.79	1.76	25.93	0.11	1.93	4.74	1.51	0.93	1.25
	1991	3.03	7.25	15.35	2.98	71.39	11.08	9.30	84.00	0.12	2.16	2.74	2.10	1.35	0.82
Wood	1971	1.29	1.18	9.39	3.18	84.96	0.91	1.24	136.77	0.57	1.83	3.64	1.28	1.12	1.23
	1991	2.39	6.22	11.85	1.69	77.85	1.65	7.89	479.33	0.47	1.09	1.14	0.81	0.82	0.87
Furniture & Fixture	1971	1.91	2.09	18.32	1.14	76.53	7.75	0.93	12.00	0.17	1.94	4.39	1.72	1.30	0.53
	1991	2.84	9.49	15.62	0.84	71.20	5.71	3.22	56.37	0.20	1.02	1.46	0.89	0.83	0.38
Primary Metal	1971	4.58	1.25	15.48	2.73	75.97	1.24	4.52	364.47	1.10	1.62	3.16	1.12	1.13	1.49
	1991	6.82	6.38	15.47	2.24	69.09	2.01	38.08	1891.37	1.62	1.26	1.47	0.96	0.95	0.81
Non-Metallic Min.	1971	3.67	2.15	18.88	1.89	73.40	2.19	2.25	102.77	0.63	1.65	3.39	1.29	1.19	0.70
	1991	4.46	9.63	17.68	1.07	67.16	1.92	6.89	360.03	0.62	1.59	1.58	1.01	1.02	0.41
TOTAL	**1971**	**2.49**	**1.64**	**18.19**	**3.09**	**74.59**	**2.49**	**23.97**	**961.34**	**0.56**	**1.84**	**3.70**	**1.29**	**1.14**	**9.61**
	1991	**3.52**	**7.84**	**16.96**	**2.38**	**69.30**	**3.32**	**151.18**	**4491.70**	**0.66**	**1.23**	**1.59**	**1.01**	**0.96**	**5.69**

continued...

Appendix *(cont.)*

INDUSTRY	YEAR	Kn (%)	Mg (%)	Dt (%)	Sv (%)	Gd (%)	C/I (x100)	C (M$)	1 (M$)	K/VA	Wk/Ws	Wm/Ws	Wd/Ws	Wg/Ws	EMPLOY (%)
MEDIUM-TECH															
Rubber & Plastic	1971	4.08	2.36	22.34	1.91	69.31	1.50	1.22	81.20	0.78	1.43	2.80	1.13	0.99	0.56
	1991	4.96	10.54	19.04	1.10	64.36	3.83	21.50	562.03	0.67	1.59	2.00	1.23	1.10	0.55
Paper & Allied Prod.	1971	3.90	1.58	16.77	2.61	75.13	0.50	2.16	433.63	1.02	1.64	3.41	1.18	1.17	1.54
	1991	5.46	6.68	17.02	2.12	68.72	1.49	45.25	3044.33	2.18	1.13	1.42	0.88	0.94	0.89
Fabricated Metal	1971	3.24	2.59	21.26	1.35	71.57	3.04	3.36	110.30	0.28	1.77	3.49	1.36	1.30	1.69
	1991	4.17	10.34	19.09	0.94	65.45	2.78	8.54	307.13	0.25	1.52	1.82	1.20	1.09	1.08
Machinery	1971	5.61	2.69	28.76	1.41	61.53	9.63	3.99	41.40	0.19	1.81	3.41	1.39	1.27	0.79
	1991	8.14	12.51	26.55	0.96	51.84	6.92	15.80	228.20	0.25	1.33	1.52	0.99	0.98	0.54
Transportation equip.	1971	4.65	1.20	17.25	2.60	74.29	5.34	8.78	164.43	0.43	1.56	2.65	1.11	1.07	2.07
	1991	7.20	6.65	16.13	1.91	68.12	2.90	57.12	1972.53	0.55	1.06	1.27	0.87	0.83	1.75
Other Manufacturing	1971	6.40	2.73	31.18	4.56	55.13	8.28	3.58	43.20	0.25	1.33	2.65	1.09	0.89	0.77
	1991	8.58	13.07	31.99	1.16	45.20	10.27	21.85	212.80	0.35	1.68	1.78	1.22	1.10	0.63
TOTAL	**1971**	**4.41**	**2.00**	**21.12**	**2.34**	**70.13**	**2.60**	**23.09**	**874.16**	**0.54**	**1.60**	**2.98**	**1.18**	**1.12**	**7.42**
	1991	**6.34**	**9.10**	**20.02**	**1.49**	**63.05**	**2.71**	**170.06**	**6327.02**	**0.81**	**1.28**	**1.47**	**0.97**	**0.95**	**5.44**
HIGH-TECH															
Electrical &Electronic	1971	8.99	2.53	31.77	1.39	55.32	4.56	4.11	90.20	0.38	1.81	3.25	1.29	1.11	1.66
	1991	14.87	13.05	27.63	0.93	43.52	15.78	107.20	679.27	0.26	1.64	2.13	1.27	1.05	0.98
Chemical	1971	7.58	3.67	39.29	2.79	46.67	3.84	5.99	156.03	0.99	1.65	2.95	1.24	1.17	0.99
	1991	10.65	14.49	35.48	1.95	37.44	5.15	80.80	1568.57	0.91	1.15	1.39	0.90	0.92	0.77
Printing & Publishing	1971	10.98	2.79	39.48	1.41	45.34	10.50	6.18	58.80	0.25	1.64	3.49	1.32	1.39	1.30
	1991	14.87	11.94	30.99	0.79	41.41	8.47	41.79	493.57	0.33	1.48	1.18	0.83	0.83	1.28
Refined Petroleum	1971	12.39	2.61	32.91	2.20	49.89	0.00	0.00	25.80	2.52	1.59	3.13	1.11	1.27	0.25
	1991	12.86	11.44	26.37	1.96	47.36	9.77	30.97	317.03	1.93	1.41	1.84	1.06	1.09	0.13
TOTAL	**1971**	**9.48**	**2.88**	**36.00**	**1.78**	**49.86**	**4.92**	**16.28**	**330.83**	**0.88**	**1.71**	**3.14**	**1.24**	**1.19**	**4.20**
	1991	**13.76**	**12.88**	**30.84**	**1.17**	**41.35**	**8.53**	**260.76**	**3058.44**	**0.63**	**1.39**	**1.61**	**0.97**	**0.99**	**3.16**

continued...

Appendix *(cont.)*

INDUSTRY	YEAR	Kn (%)	Mg (%)	Dt (%)	Sv (%)	Gd (%)	C/I (x100)	C (M$)	I (M$)	K/VA	Wk/Ws	Wm/Ws	Wd/Ws	Wg/Ws	EMPLOY (%)
SERVICE															
Construction	1971	2.21	1.90	8.95	1.16	85.78	0.84	2.36	282.00	0.12	2.06	4.07	1.35	1.52	6.47
	1991	3.04	7.54	12.09	0.93	76.40	5.00	76.76	1535.17	0.20	1.99	2.53	1.25	1.46	5.98
Transport. & Storage	1971	1.98	1.13	20.87	5.31	70.71	1.57	7.00	444.60	2.11	1.68	2.80	1.10	1.15	5.31
	1991	2.82	6.08	19.39	4.99	66.73	4.51	127.96	2838.37	1.59	1.49	1.70	1.05	1.16	4.11
Other Utilities	1971	8.59	1.59	30.45	3.54	55.83	6.19	40.69	657.43	5.77	1.76	2.90	1.13	1.28	1.13
	1991	14.10	7.29	30.43	1.94	46.25	6.65	346.20	5208.10	6.03	1.34	1.58	1.07	1.09	1.15
Wholesale & Retail	1971	1.72	1.75	64.67	2.88	28.98	3.85	14.47	375.30	0.24	1.90	4.59	1.41	1.39	15.96
	1991	2.32	12.05	58.80	2.37	24.47	10.42	318.08	3053.30	0.22	1.85	2.04	1.32	1.35	17.21
F.I.R.E.	1971	9.96	4.02	76.60	6.01	3.42	45.18	171.40	379.37	0.64	1.90	4.42	1.50	1.23	4.59
	1991	11.24	14.61	67.30	4.47	2.38	23.34	1201.41	5147.60	1.64	2.36	2.58	1.47	1.42	5.94
Communication	1971	9.96	4.84	63.81	1.88	19.52	2.24	14.80	659.33	2.61	1.87	1.54	1.21	1.52	2.09
	1991	13.64	10.52	51.34	0.95	23.55	9.26	384.65	4153.30	1.45	1.50	1.59	1.14	1.16	2.34
Bus. & Pers. Serv.	1971	9.83	1.56	27.31	51.60	9.70	3.92	14.65	373.50	0.20	2.97	1.79	1.33	1.73	13.83
	1991	12.63	8.09	30.12	41.64	7.51	26.66	1356.40	5087.27	0.32	2.77	2.61	1.57	1.51	23.22
TOTAL	**1971**	**5.35**	**1.99**	**42.48**	**16.83**	**33.35**	**8.36**	**265.37**	**3171.53**	**0.56**	**2.30**	**3.25**	**1.29**	**1.61**	**49.38**
	1991	**7.97**	**9.76**	**40.34**	**17.76**	**24.17**	**14.10**	**3811.46**	**27023.11**	**0.67**	**1.48**	**1.71**	**1.17**	**1.26**	**59.95**
PUBLIC SERV.															
Gov. & Educ & Health	1971	7.40	4.96	49.79	27.95	9.90	15.19	72.62	478.10	1.65	2.49	3.76	1.37	1.37	20.21
	1991	10.00	9.11	49.08	24.04	7.78	27.09	1126.67	4159.50	1.51	1.68	1.69	1.02	1.09	19.70

Kn	Knowledge occupations
Mg	Management occupations
Dt	Data occupations
Sv	Service occupations
Gd	Goods occupations
C	Computer Investment
I	Machinery & Equipment Investment
C/I	Computer Investment / M&E Investment
K/VA	Capital Stock / Value Added
Wk/Ws	Income earnings of knowledge occupations relative to service occupations
Wm/Ws	Income earnings of management occupations relative to service occupations
Wd/Ws	Income earnings of data occupations relative to service occupations
Wg/Ws	Income earnings of goods occupations relative to service occupations
EMPLOY	Industry employment share

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