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The Evolution of the Knowledge Economy

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Abstract. This paper revisits the definition of the knowledge economy (Beck, 1992) and investigates changes in knowledge-based industries between 1991 and 2001. Using the General Educational Development Reasoning (GEDR) scale (1-6), non-farm industries were classified as higher knowledge-based industries (GEDR level ≥ 5). The 2001 U.S. national industry-specific occupational employment and wage estimates data were analyzed to identify knowledge-based industries and compared with the knowledge-based industries identified in 1991. There were 41 knowledge-based industries in 1991. In 2001, knowledge-based industries had increased by 50 % to 64. Between 1991 and 2001, 27 of the original industries remained classified as knowledge-based industries, and seven industries became non-knowledge-based industries. In 2001, 37 new industries emerged as knowledge-based industries as a result of an increase in their knowledge ratio. Further, the composition of the knowledge-ratio of industries classified as knowledge-based has changed considerably over the period.

1. Introduction

In the late 20th century, national economies throughout the world experienced unprecedented economic challenges and opportunities. Technological advances in electronics, the revolution in software applications, and the expansion of telecommunication infrastructure have altered basic economic functions and agent interactions. The traditional shopping pattern, where a consumer travels to a shopping mall, is no longer 'the option' for shopping. Rather, E-retailing has become popular among many consumers in both urban and rural settings. Today, E-retailing and online banking are two other important segments of economic activity that have overtaken traditional shopping and bill payment systems. E-retailing has changed individual purchasing behavior, while business-to-business E-commerce has altered input purchase and delivery systems. These transformations have a direct link to the movement of people, the shipment of final and intermediary goods and services, and firm and household location choices.

The collective changes have had an impact on the nature of transportation systems, as well as firm and worker location decisions. Recently, several research studies focused on the relationship between the economic landscape and transportation system. Sohn (2002) found that as a result of telecommunication infrastructure development, many economic activities that were formerly located in the urban core had begun to diffuse to either the urban periphery or other non-metro areas. Further, the recent trend indicates that a considerable percentage of the labor force telecommute (work from where they reside) compared to traditional office workers. In 2005, it was estimated that there were about 45.1 million teleworkers compared to 44.4 million in 2004 (International Telework Advisory Council (ITAC), 2004). Drucker (1989) predicted this trend long before the technology bubble suggesting that "office work, rather than office workers, will do the traveling" Drucker (1989, p. 38). In a 2006, U. S. General Services Administration (GSA) commissioned study it was found that the financial benefits of telework exceeded the technology expansion costs of facilitating the telework.

All these changes are symptomatic of a changing economy over the past two decades and showing no indication that the pace of change will slow. This change is contrasted with the traditional economic proposition, where manual labor was considered an important factor of production. However, in the current economic condition, knowledge is considered an important factor. The resulting economic conditions are variously referred to as the "new" economy, "knowledge" economy, or "digital" economy. But, such alternative terminology can have different meanings for different people. There is neither a standard criterion to characterize the influence of advanced technologies on the economy, nor measures of its penetration and performance. Hayek suggested that the composition and intensity of knowledge-based industries depended on "how little the individual participants need to know in order to be able to take the right action" (Hayek, 1948, p. 86). The assessment of the knowledge-based economy is characterized by knowledge that individuals possess and its tacit nature made it harder to measure. Various methods have been adopted to measure the knowledge-based economy, i.e. of knowledge assets (Machlup, 1962); value of labor in knowledge intensive sectors (Eliasson et al., 1990); labor qualification (Burton-Jones, 1999); and the share of knowledge workers (Beck, 1992).

In this paper, we use the definition of the knowledge economy offered by Beck (1992), and examine the share of knowledge workers in industries in 2001. The remainder of the paper is organized into four sections. The next section discusses the history and definitions of the knowledge economy. In the following section, we proceed with a discussion of knowledge workers in the knowledge economy. In the final section, the industries constituting the knowledge economy are identified for 1991 and 2001.

2. Knowledge economy form and history

National and regional leaders have increasingly focused on knowledge-based economic activities, presuming that future economic prosperity will depend on knowledge-based activities and a similarly capable work force. Of course, in a sense, a knowledge-based economy has existed since the dawn of human civilization and its evolution has been based on its ever greater accumulation of knowledge over time. Societies benefited from knowledge in the form of the goods and services that were produced and made available to meet socioeconomic needs. Knowledge was incorporated into the production function in the form of human capital. In the early economic literature, there were no specific references to the importance of knowledge. Economists began to realize its importance in the late 19th century as Alfred Marshall suggested that "knowledge is our most powerful engine of production" and the organization facilitates the growth of knowledge (Marshall, 1890, p.115). In early 20th century, Schumpeter considered the "new combination of knowledge" as an important element for innovation and entrepreneurship (1911, p. 57).

Earlier in the 20th century, knowledge was neither directly measured nor incorporated in the production function. Researchers attempted to account for it through the unexplained portion of economic growth. The unexplained portion was labeled "technical change," "the human factor," "organization" or "measure of our ignorance" (Skilbeck, 1964), or "residue" (Abramowitz, 1956; OECD, 1964). In the neoclassical economic literature, innovation and entrepreneurship were considered essential ingredients of economic growth, while Schumpeter argued that technological change was the engine of economic growth (Schumpeter, 1939). Relating new knowledge to technical change, Antonelli (1998) suggested that the generation of new knowledge, in the form of technological change, resulted from the interplay of generic knowledge (codified technological knowledge with direct scientific content) and tacit knowledge (learning processes based on the specific experience of the innovator). Romer (1986; 1990) considered knowledge to be the third important factor of production. In an economically-progressive society, general knowledge and tacit knowledge work together, where scientific knowledge generation (general knowledge) leads to innovation (tacit knowledge). Although knowledge is important for economic development, it alone is not sufficient to bring about change in the absence of necessary infrastructure. Shapiro and Varian argued that "...today's breathless pace of change and the current fascination with the information economy are driven by advances in information technology and infrastructure, not by any fundamental shift in the nature or even the magnitude of the information itself" (1999, p.8).

All economies have some stock of knowledge, but those that are growing are distinguished by the generation of new knowledge derived from existing knowledge. Private knowledge (tacit knowledge), either in economies or in social organizations, may become the property of the institutions. Some sociologists argue that such knowledge is the intellectual property of a labor (Locke, 1924), while others argue that it belongs to the public and needs to be communicated and shared (McFarland, 2004; Buchanan and Campbell, 2005). Today, information that is commonly available (information commons[1]) and likely the result of the subsequent application of information, may become intellectual property. Information commons are more useful in either the economy or in an organization when it is codified, stored in the proper form, and made available for users. The advantage of storing knowledge is it can be retrieved and used in the production process, leading to further knowledge generation and updating the stock of existing knowledge.

In this process, social organizations play a pivotal role in information- or knowledge-based economic development. For example, universities, government, non-governmental and private sector organizations generate, store and disseminate knowledge, while many private sector organizations use the knowledge in production of goods and services. More importantly, the government provides the necessary infrastructure and regulations, not only to speed the flow of information but also to protect the intellectual property rights of individuals and organizations.

In economies, the functions of knowledge are characterized by four important features: (a) knowledge ages rapidly and new knowledge is constantly replacing the old; (b) scientific (including social scientific) knowledge is highly valued, and the scale and economic penetration of scientific knowledge increases through subsequent economic development phases; (c) knowledge economies are especially characterized by the exploitation of new knowledge in order to create more new knowledge; and (d) knowledge is used in the production of goods and services, and to enhance the social welfare of its citizens (Cooke 2002, p. 3-4).

The characterization and identification of knowledge is a complex process. There are kinds of knowledge (know-what, know-why, know-how and know-who) which are important for knowledge-based economies (OECD, 1996). The stock or knowledge of these 'kinds of knowledge' could vary from economy to economy, firm to firm, or region to region, and there is no clear understanding of what constitutes different kinds of knowledge. The relative lack of agreement in conceptualizing and defining the "new economy," or "knowledge economy," has hindered research in this area. The general description of the new economy is based, alternatively, on industrial composition (Goetz and Rupasingha, 2002); the degree to which industry sectors use advanced machines and management practices (McGranahan and Beale, 2002); or the relative proportion of an industry's labor force being comprised of certain managerial and professional/technical occupations (Wojan, 2000). Other research emphasized the influence and relative level of use of electronic communication and exchange, or E-commerce (Forrester Research, 2000). These are only a few examples of the alternative conceptions of the new economy. Despite the fact that each of these perspectives has relevance, there remain fundamental questions about how changing technology and knowledge will impact the prospects of places and people.

The analysis and discussion of the knowledge-based economy could proceed in two categories. In the first, emphasis is placed on firm-level production, where knowledge is considered a factor or part of a factor of production, known as the "knowledge economy" (Schumpeter, 1939). In the second category, the focus is the aggregation of firms within a geographic region with the necessary infrastructure to utilize the full potential of the knowledge economy, also known as the knowledge-based economy (Sahal, 1981; 1985). Since the latter embodies the former, and the former is part of the latter, these two categories go hand-in-hand. Much of the current literature focuses on the latter category, and, indeed, some knowledge-based regions are growing faster than others with lower aggregate knowledge levels.

The information commons, information infrastructure development programs, and advances in information-related technology industries have altered economic activities and the basic functioning of agents (consumers and producers). Antonelli (1998, p. 180) argued that "The penetration of new information and communication technologies encourage just such a trend, affecting the actual conditions of information in terms of its exchangeable parts, separating new information from the technical expertise used to generate it. New technologies provide an opportunity for business services providers to store and market knowledge, and for business services users to better access and purchase it." Recent developments have not only increased the scale and scope of information distribution, but also have made it relatively more difficult to find and retrieve the right information (Klusch, 1999). The proliferation of information along with technology development has highlighted the need of an appropriately trained labor force capable of managing and manipulating both the technology and the information thereby available. There had been a growing demand for high-skill labor in the knowledge segment of the economy. In the early 1990s much of the high-skill labor requirements were met through a mass importation of migrant workers from India and China.

Economists have always had difficulty defining the nature and scope of the knowledge-based economy.

[1] A body of knowledge and information that is available to anyone to use without the need to ask for or receive permission from another, providing any conditions placed on its use are respected. Buchanan and Campbell (2005, p. 229).

The movement and composition of industry sectors requiring highly-skilled labor makes the task of identifying this segment of the economy somewhat easier. Machlup (1962) first initiated work on defining the knowledge economy based on the intensity of the high-skill labor force and measured the knowledge intensity of different sectors in the economy. Machlup (1962) found six sub-sectors in the production sector of the economy: i) education; ii) research and development (R&D); iii) artistic creation; iv) communications media; v) information services; and vi) information technologies. Since then, knowledge-based economies have gradually grown, with some becoming dominate economic activities (Bell, 1973).

In any economy, firms play an important role as the building block of the economy and the change agent. However, in knowledge-based economies, firms play a crucial role as they (the firm) are the repository of knowledge (Nonaka and Takeuchi, 1995). Firms tend to grow faster as their repository of knowledge increases and its use in the production processes increases. In this context, Penrose (1995, p. 16) argued that "a firm's rate of growth is limited by the growth of knowledge within it." In many instances, firms consider the repository knowledge as their most valuable asset.

Over the years, researches were able to develop criteria to measure the intangible nature of the knowledge in regions and in firms in particular. Recently, Sánchez et al. (2000) introduced a guideline to measure a firm's knowledge by distingushing intangible resources, intangible activities, and having performance indicators. Then, the level of activity or stock of an identified variable of an intangible is measured (ratios or numbers). These numbers or ratios could be compared across firms, regions and economies.

3. Measuring knowledge firms, industry, and the economy

Measuring the knowledge level of a firm is just as difficult as gauging the overall knowledge of an economy. Firms replace or update their repository of knowledge through an iterative process in maintaining a high-skill workforce and providing opportunities to develop those skills (education and training) on a regular basis. In this context, the knowledge level of a firm can be measured as a stock or flow. In measuring the stock of knowledge either in a firm or region, the knowledge workers play a crucial role in determining the level of stock. Davenport (2005, p.10) identified a knowledge worker as "someone with high degrees of expertise, education or experience and the primary purpose of their job involves the creation, distribution, or application of knowledge", while Drucker (1969) found knowledge workers to be those who process existing information to new information. Surprisingly, Kogan and Muller (2006) suggested that the knowledge workers get their work done in a process-oriented environment. Knowledge workers are employed in firms to perform a function and to contribute their share in the production of goods and service. In the process-oriented environment, functional knowledge stock (utilization of knowledge stock) is considered as the flow of knowledge, and knowledge workers are less of a stock than flow. By measuring the knowledge workers, one could potentially measure both the stock and the flow.

The current literature offers few methodological underpinnings to measure the knowledge level of a firm, region or economy. Measuring knowledge is a complex process, with the perfect criterion to measure the knowledge yet to be found. Shapira et al. (2006, p.1528) note that "there is no agreement on the right proxy of "knowledge" to be used. While the development of indices to measure knowledge is interesting, such indices are generally available only at the national level. More fundamentally they tend to be "data-driven" (using that data which is available across countries) rather than "conceptually-driven" (e.g. being based on a model of knowledge acquisition and use and relationships to innovation and economic performance)." Further, Shapira et al. (2006) suggest the measurement of knowledge at the industry scale provides a more detailed comparison in contrast to macro- or micro-level measures. In this paper, all industries in the U.S. economy are examined to assess their knowledge level using the level of workers as an indicator. Beck (1992, p. 125) suggested that three types of workers qualify as a knowledge worker:

1. Professionals, such as doctors, engineers, lawyers, accountants and actuaries. The demand for their skills and information has created dramatic growth in professional services. This employment category is associated with educational level.

2. Engineering, scientific and technical workers. This employment category is not based on educational attainment, but rather with acquired specialized skills.

3. The very senior ranks of management, who are important to determine the strategic focus of a firm.

It is difficult to find all three types of knowledge workers in an average knowledge-based firm. However, in knowledge-based firms, the combined intensity of knowledge workers (the ratio between knowledge workers and total workers) would be high. Beck (1992, p.125) called this ratio the "Knowledge Ratio."

A knowledge worker can be identified based on the function that he/she performs or the occupational title of the employee. An employee's occupational title reflects the skill level required to perform an occupation. The U.S. Department of Labor annually publishes the "Dictionary of Occupational Titles" that identifies the cognitive skills required of the occupation. The General Educational Development-Reasoning Scale (GEDR), used to measure the skill level of different occupations, provides an ordinal ranking of cognitive requirements ranging from the ability to follow simple instruction to the ability to solve complex problems (Wojan 2000, p.597). The GEDR for different occupational classifications (Wojan 2000, p.598) are presented in Table 1. Knowledge workers require higher-level cognitive skills as compared to non-knowledge workers. While Beck (1992) did not use the GEDR in defining knowledge workers, later evaluations confirmed the criteria used in the definition were consistent with the notion of knowledge workers.

Table 1. Skills Requirements Distribution (%) by Summary Occupations Unweighted Detail Occupations from the *Dictionary of Occupational Titles*

	General Educational Reasoning Scale					
Occupational Category	GEDR 1	GEDR 2	GEDR 3	GEDR 4	GEDR 5	GEDR 6
Managers	0	0	4.54	44.59	46.16	4.71
Professional/Technical	0	0.23	2.80	18.27	42.17	36.51
Sales	0.15	2.25	21.35	64.81	11.42	0
Technical	0.23	7.20	56.55	34.59	1.29	0.11
Precision Production	0.99	10.94	29.77	58.02	0.26	0
Operators	5.62	50.75	37.42	5.97	0.21	0.02
Service Occupations	2.94	24.88	46.15	23.07	2.94	0
Laborers	38.52	57.32	4.14	0	0	0
Farm, Forestry and Fisheries	8.08	26.41	27.49	26.68	11.32	0
All Occupations	4.65	23.96	25.11	26.49	12.32	7.43

Source: U.S. Department of Labor, 1991; 1994

GEDR 1. Apply common sense understanding to carry out simple one- or two-step instructions. Deal with standardized situations with occasional or no variables in or from these situations encountered on the job.

GEDR 2. Apply common sense understanding to carry out detailed but uninvolved written or oral instructions. Deal with problems involving a few concrete variables in or from standardized situations.

GEDR 3. Apply common sense understanding to carry out instructions furnished in written, oral, or diagrammatic form. Deal with problems involving several concrete variables in or from standardized situations.

GEDR 4. Apply principles of rational systems* to solve practical problems and deal with a variety of concrete variables in situations where only limited standardization exists. Interpret a variety of instructions furnished in written, oral, diagrammatic, or schedule form.* Examples of rational systems are: bookkeeping, internal combustion engines, electric wiring systems, house building, farm management, and navigation.

GEDR 5. Apply principles of logical or scientific thinking to define problems, collect data, establish facts, and draw valid conclusions. Interpret an extensive variety of technical instructions in mathematical or diagrammatic form. Deal with several abstract and concrete variables.

GEDR 6. Apply principles of logical or scientific thinking to a wide range of intellectual and practical problems Deal with nonverbal symbolism (formulas, scientific equations, graphs, musical notes, etc.) in its most difficult phases. Deal with a variety of abstract and concrete variables. Apprehend the most abstruse classes of concepts.

The complexity and relative usefulness of using firm-level data in examining the knowledge-based economy makes it an inappropriate unit of analysis with which to measure macroeconomic performance. Generally, macroeconomic performance is evaluated at levels of aggregation greater than the firm. More typically, it is at the scale of industries. Based on the Knowledge Ratio, Beck (1992, p.128) classified industries into three categories:

Table 2. Summary Statistics of Data

Occupations	Mean Industry Employment	Percent of Occupation in the Industry	Mean Annual Wages
Management	19,283	6.52	73,183.98
	(39,011)	(3.72)	(13,073)
Business and Financial Operations	13,060	3.99	48,203.49
	(36,616)	(6.16)	(66,35.64)
Computer and Mathematical	8,760	1.97	53,362.80
	(55,729)	(3.94)	(6,762.51)
Architecture and Engineering	8,548	2.85	53,833.21
	(36,355)	(5.37)	(8,416.19)
Life, Physical, and Social Science	3,963	1.14	49,593.69
	(15,325)	(2.41)	(9,105.48)
Community and Social Services	25,375	2.93	34,993.33
	(57,568)	(6.29)	(11,002.53)
Legal	6,159	1.09	78,288.37
	(42,717)	(5.19)	(19,392.92)
Education, Training, and Library	67,694	3.90	37,075.04
	(501,995)	(11.97)	(9,755.32)
Arts, Design, Entertainment, Sports, and Media	5,302	2.19	40,307.36
	(161,48)	(7.06)	(8,948.47)
Healthcare Practitioners and Technical	31,515	2.59	45,617.53
	(197,246)	(8.21)	(8,497.76)
Healthcare Support	47,267	4.60	23,668.94
	(130,644)	(9.17)	(4,890.27)
Protective Service	10,894	0.75	26,503.62
	(89,102)	(2.95)	(6,216.4)
Food Preparation and Serving Related	68,370	4.26	19,479.52
	(595,318)	(10.64)	(4,174.79)
Building and Grounds Cleaning and Maintenance	12,572	2.02	21,477.85
	(66,743)	(7.07)	(3,738.01)
Personal Care and Service	22,355	5.74	22,492.80
	(59,166)	(13.48)	(6,266.78)
Sales and Related	37,066	11.24	41,610.88
	(124,215)	(18.5)	(14,034.16)
Office and Administrative Support	60,473	17.12	27,574.43
	(145,134)	(12.67)	(4,237.79)
Farming, Fishing, and Forestry	5,592	4.19	22,874.63
	(18,763)	(13.96)	(5,561.13)
Carpenters	21,801	6.93	35,428.78
	(84,836)	(16.74)	(6,147.55)
Installation, Maintenance, and Repair	14,619	5.95	33,533.87
	(40,226)	(7.85)	(5,969.75)
Production	33,045	24.33	28,465.57
	(66,713)	(25.7)	(7,125.02)
Transportation and Material Moving	26,274	11.07	25,730.75
	(83,588)	(14.75)	(6,555.1)

Note: Figures below in the parentheses are standard deviation

1. High-knowledge-intensive industries – having Knowledge Ratios of 40 % or more;
2. Moderate-knowledge-intensive industries – clustering between 20 and 40% of the Knowledge Ratio scale.
3. Low-knowledge-intensive industries – industries that stand below 20% on the scale.

Based on the knowledge ratio, the industries are ranked from higher-knowledge-intensive to lower-knowledge-intensive industries. This classification system is a relative classification rather than the absolute measure of knowledge level of an industry. For example, the knowledge ratio of 39.4% would be considered as moderate-knowledge-intensive industry, while 34.6% could be considered as high-knowledge-intensive industry. In this paper, the same classification system is used to examine knowledge-based industries in 1991 and 2001.The measurement of knowledge workers (knowledge ratio) may not be the ideal way to characterize the knowledge-based economy, i.e. labeling other workers in an implied inferior occupational category. Through the knowledge filtration process, however, individuals in the other occupational category can advance to knowledge-based occupations. Technology is likely to play a crucial role in knowledge-based firms and their competitiveness. A significant benefit of knowledge can be derived from managing the knowledge (i.e. 'knowledge management'). Hibbard and Carrillo (1998) argued that in organizations, the concepts and processes that are in place are important, and businesses were likely to discover more value in effective knowledge management process rather than upgrading software or technology. Organizations manage their knowledge through many processes, and knowledge filtering is an important part of that process. Focusing on the knowledge-intensive occupations to measure the knowledge-based economy can underestimate the knowledge level of a firm or industry. However, potential knowledge-intensive workers are filtered from non-knowledge-intensive occupations and promoted as knowledge-based-level occupations. On the other hand, those who possess knowledge (in non-knowledge intensive occupations) and not being rewarded to that knowledge potential may voluntarily leave the organization.

4. Data

The U.S. national Occupational Employment Statistics (OES) data from the Bureau of Labor Statistics (BLS) were used in this analysis. The OES data measure the occupational employment and wage rates for wage and salary workers in non-farm establishments in the U.S. The OES data are collected from a survey of employers in all industry sectors in metropolitan and non-metropolitan areas of the U.S. The OES survey uses the Office of Management and Budget's (OMB) occupational classification system, the Standard Occupational Classification (SOC) system. The SOC system is the first OMB-required occupational classification system for federal agencies. The OES survey categorizes workers in one of 801 detailed occupations. Together, these detailed occupations comprise 23 major occupational groups, one of which is the military specific occupations, which is not included in the OES survey (BLS, 2006). The data are available from 1997 to 2005 and can be downloaded from the BLS Website.

Prior to 2001, industries were identified by the Standard Industrial Classification (SIC) Code at the two- and three-digit SIC level. Since 2002, industries have been identified using the North American Industry Classification System (NAICS) at the three, four- and five-digit NAICS level. At the time of this data analysis, it was impossible to identify comparable data for any years prior to 1997. However, Wojan (2000) noted that based on the Census of Population, occupational employment data were available in the U.S. Department of Commerce publications in 1972, 1982 and 1992. In this study, the 2001 U.S. national Occupational Employment Statistics (OES) data are used. The data consist of 379 industries at the three-digit SIC code and 22 major occupations. Summary statistics of the data are presented in Table 2. These data present mean annual employment of an industry, mean percent of occupation in the industry, and mean annual wages of the occupations.

5. Knowledge-based Industries 1991 & 2001

Beck (1992) estimated the knowledge ratio of all major industries in the U.S. and classified them into high, medium, and lower-intensive industries. In this study, 1991 knowledge-based industries were identified using Beck's (1992) classification with an exception that they were approximated at a three-digit SIC level. According to Beck's (1992) classification, there were 41 high-knowledge-intensive industries (including government administration) in 1991. There were seven government administration industries that were classified as high-knowledge-intensive industries.

The knowledge ratios for industries were estimated using the 2001 OES data. Industry data were used at three-digit aggregation level. In this study, ten types of workers (occupations) are identified as the knowledge workers:

1. Management Occupations
2. Business and Financial Operations Occupations
3. Computer and Mathematical Occupations
4. Architecture and Engineering Occupations
5. Legal Occupations
6. Arts, Design, Entertainment, Sports, and Media Occupations
7. Healthcare Practitioners and Technical Occupations
8. Life, Physical, and Social Science Occupations
9. Education, Training, and Library Occupations
10. Healthcare Support Occupations

The knowledge ratio (the ratio between the number of knowledge workers and total workers) was estimated for the industries and the industries were classified as knowledge-based industries if their knowledge ratio scale (KR) was greater than or equal to forty (KR ≥ 40). The knowledge-based industries in 1991, 2001, their knowledge ratio, and the change in knowledge ratio between 1991 and 2001 are shown in Appendix 1.

The broader objective of this paper is to examine the evolution of knowledge-based industries between 1991 and 2001. A fair comparison of industries warrants the industry classification system remains unchanged between these two periods. However, there was a major revision in the industry classification system in 1997. The North American Industry Classification System (NAICS) was introduced in 1997. In 1998, the 1980 Standard Occupational Classification (SOC) was revised and a new coding system was introduced. Despite the introduction of NAICS coding system in 1997, the U.S. Department of Labor (Bureau of Labor Statistics) continued to publish the OES data based on 1987 SIC coding system but with a revised Standard Occupational Classification (SOC) codes system until 2001. With the revised SOC system, new occupations were added and some occupations were reclassified into other categories. This industry reclassification in 1998 complicates the analysis and comparison between 1991 and 2001. As a result, some of the industries were eliminated in the analysis based on the following criteria:

1. The industries present in 1991 but not in 2001.
2. The industries present in 2001 but not in 1991.

The overall results indicate that the number of industries classified as knowledge-based increased by 50% to 64 by 2001. Between 1991 and 2001, 27 of the original industries remained as knowledge-based industries. In 2001, 37 new industries emerged as knowledge-based industries as a result of an increase in their knowledge ratios (10 industries) and new SOC classification (27 industries). Seven of the knowledge-based industries in 1991 became non-knowledge-based industries in 2001. The 27 industries that emerged as knowledge-based industries due to the SOC reclassification were eliminated from the analysis. The results are presented for the remaining 44 industries. Selected industries are discussed in this paper.

Considering some of the major changes and their potential origins as observed in Appendix 1, it appears that there were likely multiple and complex economic phenomena at play. In all instances discussed here, industry-specific forces contributed to the changes that were observed and identified. Underlying all of this, however, are likely to be larger, more global economic forces involved. Some of these might include the rise of information and communication technologies; the increasing globalization of competition; the bifurcation of functions within industries as separate activities are situated in their most conducive location; and the application of capital-intensive technologies that routinize many formerly-skilled activities. Recognizing these complexities, the results discussed here are left largely to speculate about the nature of changes in the knowledge economy. Nonetheless, it is instructive to contemplate change and its genesis.

Some industries showed a significant reduction in the knowledge ratio. For example, secondary smelting and refining of nonferrous metals, retail stores (not elsewhere classified), and funeral service and crematories experienced more than a 50% reduction in their knowledge ratios. It was noted that in mid-1990, the secondary smelting and refining of nonferrous metals industry began to recycle consumer metal waste. However, the major reduction in the industry's knowledge workers was reportedly due to the growing imports of virgin and recycled materials from other countries. Scott (1996) found that imports from Canada and Mexico cost the U.S. about 430 jobs in 1995 and continue to drain domestic industry employment opportunities today.

The religious organizations' knowledge ratio declined by almost 50% in the decade under study. The service requirements of these organization's members depend on the level of membership. A recent study suggested that in 2000 about 50.2% of Americans were associated with a religious organization compared to 55% in 1990 (Donovan, 2002).

The 27% reduction in the knowledge ratio in management and public relations services industry was somewhat surprising. The primary function of the industry is to help other organizations in strategic and organizational planning, as well as the preparation of communication materials (written or spoken) on behalf of organizations. With the information revolution, web-based communication became more popular and cost effective, which may have reduced the demand for the services of this industry.

The advertising industry knowledge ratio declined to 45% from 58%. Information technology, internet-based communication, fragmentation of consumer markets, and the general erosion of mainstream media changed the dynamics of advertising. Electronic technology is used to design and deliver product and service information. Further, the technology-aided direct-to-consumer (DTC) advertising became popular in western economies, which may have reduced the demand for knowledge workers in the industry.

Museum and art galleries are an important component of the knowledge-based economy, being integrated within the larger tourism industry. Creativity is an essential element of art. However, the analysis shows that the industry's knowledge ratio declined by about 20% during the study period, and by 2001 it became a non-knowledge-based industry. Information and communication technology helped to transform the structure and conduct of the industry. Digitalization of images and art works led to the creation of digital archives and museums, which in some ways may facilitate the destruction of the artistic value creation process. While the digitalization of art and museums created new opportunities for "digital value creation," the social costs may exceed the benefits. For example, the recent digital re-creation of works such as the Mona Lisa has changed both the perception of art and the marginal cost of reproducing art. Reduction of the marginal cost of reproduction would likely lead to the reduced value (price) of the art, thereby reducing value creation rather than enhancing it. Doyle (2001) found it was difficult to make money from investment in internet interactivity and multimedia products. Further, a traveler with a home computer and access to the Internet no longer needs to go to France to view the Mona Lisa. In the long run, "virtual museums" or "digitalization of art" may hurt the tourism industry and the economies that are dependent on art and museums. Apart from technology, museums and the art industry also suffered from cutbacks in funding support (Webster, 1995), reduced educational funding in the arts and humanities disciplines (Bercuson et al., 1997), and a lack of human capital development through the diversion of quality students to business-oriented training (Ungar, 2003).

While the accounting, auditing, and bookkeeping services industry's knowledge ratio dropped by about 16%, it remains a knowledge-based industry. Electronic tax filing, outsourcing and customized accounting and bookkeeping systems potentially allow fewer high-knowledge professionals to do more relative to overall U.S. industry employment.

Conversely, the drugs industry became a non-knowledge-based industry by 2001. The decline of knowledge-based professionals within the industry was attributed to lack of entry professionals into the industry. The U.S. drugs industry is experiencing an acute shortage of pharmacists and often seeks professionals from overseas labor markets such as from South Africa, India and United Kingdom to replenish its ranks (Frederick, 2001).

Some of the knowledge-based industries' ratios changed very little (less than 5%) between 1991 and 2001. These industries included: vocational schools; laboratory apparatus and analytical, optical, measuring, and controlling instruments; miscellaneous health and allied services, not elsewhere classified; radio and television broadcasting stations; computer programming, data processing, and other computer related services; and communications equipment. Still other industries had remarkable increases in their knowledge ratios and became knowledge-based industries by 2001. Security and commodity exchanges; theatrical producers (except motion picture); life insurance; nursing and personal care facilities; and search, detection, navigation, guidance, aeronautical, and nautical systems, instruments, and equipment industries experienced more than 50% growth in the knowledge ratio.

The periodicals publishing, or publishing and printing industry's 48% growth in the knowledge ratio was somewhat surprising. With the proliferation of internet media, the publishing industry was supposed to be hard-hit with revenue losses from advertising and the expansion of online news outlets. In July 2006, the World Association of Newspapers reported the outsourcing of media jobs had become common in the industry and would likely hurt the domestic publishing industry. Recently, major newspapers reported a daily circulation decline of 2.6% for the six months period ending September 30, 2007 (Hau, 2007). Regional printing centers have eliminated extensive distribution networks, and publishers frequently rely on other publishers or use common distributors for delivery (Regan, 1996). The current state of the industry raises an interesting question about the relationship of the knowledge ratio and overall industry employment. It would seem that it would depend on the types of jobs/functions that are outsourced. Outsourcing of non-knowledge-based occupations increases the share of knowledge-based occupations, thereby contributing to an increase in the knowledge ratio. In this case, to the extent outsourcing was indeed a factor, the bulk of the outsourced jobs/activities occurred in non-knowledge-based occupations.

The child day care services industry's knowledge ratio increased by about 34% between 1991 and 2001. There is a growing demand for child day care services "as the increase in two-income households and the number of pre-school-aged children help make day care a ripe market, just as the trend toward more use of temporary employees stimulated demand for personnel-supply services" (McCune, 1995, p. 50). One might have expected this industry would be less knowledge-based compared to many other industries. The industry has a higher knowledge ratio partially as a result of its evolution to a more professional industry (e.g. having accreditation standards (McCune, 1995)), and partially as a result of industry structure and occupational accounting. Using the Statistics of Income Division, U.S. Internal Revenue Service (SOI) data, Lowrey (2005) reported that in 1997, about 73% of U.S. business firms were operating as sole proprietorships. U.S. Small Business Administration statistics show that about 70% of child day care industry businesses have fewer than 20 employees. If the majority of child day care service providers fall into the sole proprietor category, the owners also would be managers. As a result of being classified within the management category, the knowledge ratio in the industry is relatively high.

The 92% increase in the knowledge ratio of nursing and personal care facilities may be associated with demographic shifts toward an older population. According to 2005 Medicare estimates, about nine million elderly expected to use a long-term care service. That number was projected to grow to 12 million by 2020. The growing demand for services has increased the industry's share of total employment. Further, structural adjustments within the industry have altered the composition of occupations. Service providers are increasingly investing in technology to integrate functional and clinical service provision and to reduce costs (Burns et al., 1997), and to eliminate unnecessary administrative costs and inappropriate care (Gilles et al., 1993). These capital investments provide better information-sharing systems through network providers, and high-level management capacity for examining individual client consumer and physician behavior (Coburn, 2001). The introduction of "Robotics Assistants" in nursing homes is a good example of effective technology use in this industry. Through the *Nursebot project*, a team of multi-disciplinary experts developed a prototype robotic assistant, and "the robot demonstrated the ability to contact a resident, remind them of an appointment, accompany them to that appointment, as well as provide information of interest to that person, for example weather reports or television schedules" in a nursing home (Pineau et al., 2003).

The life insurance industry has shown a 90% increase in its knowledge ratio and became classified as a knowledge-based industry. In the mid-1990s, insurance companies introduced online services, including price comparisons (Dugas, 1999). Internet-based commerce commonly eliminates intermediary agents between the firm and the customer, and potentially reduces the cost associated with life insurance. Brown and Goolsbee (2000) reported that between 1993 and 1997, the cost per $1,000 one-year renewable policy had been reduced more than 20%. The cost reduction was likely achieved through labor cost savings. By examining the technology used in insurance industry, Yates (2005) found that the insurance industry was gradually adopting information processing technologies. They subsequently benefited in a variety of ways including simplification of information processing and decision making, and creating a new learning environment by recruiting and training knowledge workers such as programmers, system analysts, program librarians, computer operators, and data-entry clerks.

Similar to the insurance industry, other industries that observed a considerable growth in their knowledge ratio benefited from application of new information technologies which, in turn, reshaped the industry occupational composition.

6. Conclusions

This study suggests that there is considerable dynamism in the knowledge intensity within and across industry sectors. About 52% of high-knowledge-based industries in 1991 had been transformed into non-knowledge-intensive industries by 2001, while 10% of non-knowledge-based industries became knowledge-intensive industries by 2001. One striking finding among the results was the extent to which many supposedly professional industries have been classified downward, while many other service industries have shifted higher on the knowledge-intensity scale. Some of these new industries were found in manufacturing, such as secondary smelting and refining of nonferrous metals, that had become non-knowledge-intensive industries. Other industries that were traditionally considered to be non-knowledge-intensive industries were found to be knowledge-intensive (e.g. child day care service and nursing and personal care facilities). While the data hold few clues to what may be occurring, it might be speculated that information technologies have helped to routinize many functions previously performed by more highly-skilled professionals. Further, telecommunications advances permitted the bifurcation of many industry functions and the outsourcing of lower-skill jobs. Finally, advancing technologies may have transformed many of the 'old-line' industries into automated high-technology operations requiring less low-skill manual labor and more advanced technical skills.

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Appendix 1 Knowledge-Based Industries in 1991 and 2001 at Three-Digit SIC

SIC Code	SIC Title	Knowledge Ratio 1991	Knowledge Ratio 2001	Percentage Change
334	Secondary Smelting and Refining of Nonferrous Metals	61	12	-80.33
726	Funeral Service and Crematories	63	29	-53.97
599	Retail Stores, not elsewhere classified	45	21	-53.33
866	Religious Organizations	62	32	-48.39
842	Arboreta and Botanical or Zoological Gardens	46	26	-43.48
874	Management and Public Relations Services	74	54	-27.03
839	Social Services, not elsewhere classified	53	40	-24.53
731	Advertising	58	45	-22.41
841	Museums and Art Galleries	46	37	-19.57
872	Accounting, Auditing, and Bookkeeping Services	67	56	-16.42
283	Drugs	46	39	-15.22
829	Schools and Educational Services, not elsewhere classified	83	71	-14.46
811	Legal Services	61	53	-13.11
873	Research, Development, and Testing Services	76	67	-11.84
482	Telegraph and Other Message Communications	72	64	-11.11
781	Motion Picture Production and Allied Services	67	60	-10.45
611	Federal and Federally-Sponsored Credit Agencies	44	40	-9.09
376	Guided Missiles and Space Vehicles and Parts	69	65	-5.80
871	Engineering, Architectural, and Surveying	84	80	-4.76
824	Vocational Schools	71	68	-4.23
382	Laboratory Apparatus and Analytical, Optical, Measuring, and Controlling Instruments	41	41	0.00
809	Miscellaneous Health and Allied Services, not elsewhere classified	53	53	0.00
483	Radio and Television Broadcasting Stations	72	72	0.00
737	Computer Programming, Data Processing, and Other Computer Related Services	72	72	0.00
366	Communications Equipment	45	47	4.44
803	Offices and Clinics of Doctors of Osteopathy	53	56	5.66
131	Crude Petroleum and Natural Gas	39	42	7.69
821	Elementary and Secondary Schools	66	72	9.09
822	Colleges, Universities, Professional Schools, and Junior Colleges	61	67	9.84
291	Petroleum Refining	37	41	10.81
372	Aircraft and Parts	37	41	10.81
801	Offices and Clinics of Doctors of Medicine	55	61	10.91
862	Professional Membership Organizations	50	57	14.00
806	Hospitals	59	71	20.34
804	Offices and Clinics of Other Health Practitioners	49	60	22.45
357	Computer and Office Equipment	45	59	31.11
835	Child Day Care Services	47	63	34.04
802	Offices and Clinics of Dentists	49	69	40.82
272	Periodicals Publishing, or Publishing and Printing	29	43	48.28
623	Security and Commodity Exchanges	31	55	77.42
792	Theatrical Producers (except Motion Picture)	34	61	79.41
631	Life Insurance	22	42	90.91
805	Nursing and Personal Care Facilities	28	67	139.29
381	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems, Instruments, and Equipment	23	66	186.96