The Diagnostic Imaging Equipment Industry: What Prognosis for Good Jobs?

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Working Paper No. 224

January 1998

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For helpful comments on earlier drafts, we thank Beth Almeida, Robert Forrant, William Lazonick, William Mass, Philip Moss, Mary O'Sullivan, and Harold Salzman.

Introduction

The U.S. diagnostic imaging equipment industry stands astride several of the most noteworthy trends in the current U.S. economy. Diagnostic imaging equipment, which includes such machines as x-ray machines, CT (computed tomography) scanners, and MR (magnetic resonance) scanners, forms visual images of areas within the body for diagnostic purposes. Thus, although the diagnostic imaging equipment industry is a manufacturing industry, its fate is closely tied to the service sector--and specifically to health care. Diagnostic imaging shared in the meteoric rise of health care spending over the last several decades. Now it shares the effects of managed care and other concerted efforts at health care cost containment.

Diagnostic imaging equipment is also a high technology industry. The design of such equipment is extremely engineering-intensive--combining mechanical and electrical engineering with the specialized engineering involved in regulating various forms of radiation. New technological generations of CT or MR scanners succeed each other every few years, not unlike personal computers. The combination of safety concerns with enormous complexity renders these instruments among the most technologically sophisticated products manufactured in the world today. Unlike computers, however, diagnostic imaging machines are typically produced in small batches. The entire U.S. output of CT scanners in a given year can be counted in hundreds, and the price tag for a single high-end CT or MR machine typically exceeds one million dollars.

Thus, while diagnostic imaging equipment is not by any means a typical industry, it offers an example of a rapidly changing, high technology sector--the kind of industry in which, according to many observers, United States manufacturers ought to excel. And indeed, for most of the hundred-year history of this industry, U.S. producers have led the field, generating engineering jobs aplenty and production jobs paying well above the average wage economy-wide. But in the last two decades, there have been dramatic transformations, which have changed the face of the industry and pose new challenges for U.S. companies. In the process, while world diagnostic imaging equipment leader General Electric has successfully maintained and even slightly increased its market share, second-tier U.S. producers have lost ground to Japanese and European manufacturers.

The process of economic change in the industry can be summarized in four propositions.

1) Thirty-five years of rapid growth in U.S. demand may be coming to an end, making the international market increasingly important. Since the early 1960s, demand for diagnostic imaging equipment has expanded vigorously. In addition, and helping to fuel the demand, there has been an exuberant run of innovation. As of the early 1960s, the diagnostic imaging industry consisted of x-ray machinery alone. As of the late 1990s, there are substantial markets in addition for four other major forms of diagnostic imaging equipment (CT, MR, ultrasound, nuclear medical instruments), as well as a number of smaller markets (for example, positron emission tomography [PET], picture archiving and communication systems [PACS]). However, the rise of managed care in the world's largest market for diagnostic imaging, the United States, along with fiscal pressures in Western Europe, appear to be causing growth in these mature markets to level off. Rapid demand growth in the future is likely to occur in developing countries.

2) U.S. producers have undertaken outsourcing and downsizing. Companies have downsized in response to dips in the market for particular products, as well as the long-term flattening of health care demand. U.S. companies' outsourcing of components has shifted many production and some engineering to smaller companies. The net impact of outsourcing on high quality jobs is unclear, since it decreases good jobs in the company, but is likely to improve jobs in the suppliers.

3) Japanese producers have made significant inroads into the global and U.S. diagnostic imaging equipment markets. For the first seventy years of the diagnostic imaging industry, U.S. and European producers held sway, particularly in their home markets. But over the last 30 years, Japanese producers have entered and steadily expanded their market share. In addition to producing equipment under their own brand names, Japanese manufacturers—acting as suppliers, joint venture partners, or subsidiaries—have supplied components and complete machines to be sold by U.S. and European companies.

4) There is some evidence that U.S. companies have carried out less organizational integration of suppliers, engineers, and production workers than Japanese producers. By organizational integration, we mean the integration of productive actors into learning and decision-making activities. The existing case study literature has not paid enough attention to workforce issues to adequately assess the state of organizational integration in U.S. companies, let alone to demonstrate the connection between organizational integration on the one hand, and job quality and competitiveness on the other. However, the limited evidence we have been able to find suggests that, as in other industries, U.S. producers have achieved less organizational integration of certain groups than have their Japanese counterparts.

To trace this recent history, this paper draws on the case study literature on diagnostic imaging, on publicly available industry data, and on the business press. It also incorporates very preliminary findings from interviews and site visits by the author and others at five diagnostic imaging companies, two in the United States and three in Japan. At the companies' request, their identities must currently remain confidential. Some of the company-based research has been supported by the Sloan Foundation through a project entitled "Corporate Restructuring, Skill Formation, and Earnings Inequality".[1]

The paper unfolds in four sections that mirror the four propositions. Each section summarizes both quantitative trends and case study evidence. The evidence available from published sources, coupled with preliminary interview findings, reveal quite a few interesting patterns, but also leave a great deal unanswered. Consequently, we follow these four sections with a brief conclusion making the case for additional case study research and sketching directions for such future research.

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[1] The project is headed by Harold Salzman of Jobs for the Future (a Boston-based nonprofit research organization focusing on employment, training, and education), and includes Philip Moss and Chris Tilly of the University of Massachusetts at Lowell as senior investigators.

1) Growth of the diagnostic imaging industry

An introduction to diagnostic imaging

The diagnostic imaging equipment industry produces machines that visualize structures and processes inside the human body for the purposes of medical diagnosis. Currently, diagnostic imaging embraces six main types of equipment, often called "modalities"[2]:

1) Conventional x-ray equipment. Conventional x-ray equipment, the oldest modality, dates back to 1896. Conventional x-ray machines pass x-rays through the patient's body to a piece of film. Because x-rays are selectively deflected by areas of greater density (particularly bone), the resulting image shows structures within the patient's body. X-rays are often used in conjunction with contrast media, chemicals injected or ingested within the patient to highlight particular anatomical features.

2) Nuclear medical instruments. Unlike other diagnostic imaging modalities, nuclear medicine uses the patient's **body** as the radiation source. Radionuclides (radioactive substances that emit gamma rays) are ingested by or injected into the patient, and then a detector is used to form a visual image of these radioactive materials within the body. This method depends on radiopharmaceuticals that are absorbed selectively by particular organs, or absorbed at different rates by healthy and diseased tissue. The first viable nuclear medical imaging machine went on sale in 1959. Nuclear medicine is relatively non-invasive and particularly useful for examining physiological functions (since sequential images can track the uptake of marker chemicals by an organ), but offers lower resolution than other modalities.

Nuclear medicine has given rise to two specialized spin-offs. **Single photon emission computed tomography (SPECT)** detects photons emitted by the radionuclides, and saw product launches in the mid-1970s. **Positron emission tomography (PET)**, in turn, specifically detects photons created by positrons (positively charged electrons) generated by decay of the radionuclides. Commercial PET systems first appeared in the late 1970s. Despite the hopes of their innovators, neither SPECT nor PET has yet become a large market.

3) Ultrasonic imaging equipment. Ultrasound equipment passes high-frequency sound waves, rather than x-rays, through the body to form an image by the same methods as sonar. The first commercial ultrasonic imager appeared in 1963, but the breakthrough in ultrasound technology occurred in 1974, when a small company, Rohe Scientific, developed a the first practical stored video "gray scale," permitting far greater resolution than previous black-and-white systems. Ultrasound imaging does not use ionizing radiation or invasive contrast media, and therefore is the method of choice for visualizing the fetus in utero. Ultrasound is also less expensive than other modalities, but ultrasound images are more difficult to interpret than those formed by other methods (Friar 1987).

4) Computed tomography (CT) scanners. CT scanners, first sold in 1972, once more use x-rays. A CT scanner beams x-rays at detectors at a series of specified positions and angles,

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[2] This description of the modalities draws on IDD 1995, McKay 1983, and Mitchell 1988.

in order to create images of a series of thin slices of the body. This series of slices allows physicians to visualize structures inside the body in three dimensions. CT scanning can distinguish among 2000 levels of density, whereas standard radiography can only distinguish among 20. However, CT scans are considerably more expensive.

5) Magnetic resonance imaging (MR, or MRI) equipment. Magnetic resonance exploits the fact that atomic nuclei of various elements align themselves in distinctive ways when subject to a strong magnetic field. A MR scanner applies such a field, then transmits radio waves, resulting in the release of energy that can be used to map structure and/or function. The first MR imaging machines were marketed in 1980. MR scanning provides very sharp images without ionizing radiation, but remains quite expensive. The potential of using MR scanners to analyze chemical changes (that is, physiological function) as well as anatomical structure, touted by MR producers since the modality's inception, has not yet been fully realized, though a small market for functional MR equipment exists.

6) Digital radiography equipment. Digital radiography uses the same principle as conventional x-rays, creating two-dimensional images of the body. However, digital x-ray equipment, first marketed commercially in 1981, captures images on a detector rather than a piece of film, so that the information in the images can be manipulated by computer systems. One standard application is "digital subtraction": an area of the body is x-rayed with and without a contrast medium, and the resulting images are digitally subtracted to sharply focus on where the contrast medium has been taken up by the body. Digital radiography offers greater resolution than conventional radiography (and allows use of smaller amounts of invasive contrast media), but at lower cost than CT scanning.

In addition to these six main modalities, the diagnostic imaging industry sells equipment designed to manage images created by a variety of modalities:

7) Picture archiving and communication systems (PACS). PACS are computer systems that electronically record and archive images generated by any of the previous six modalities. PACS, often called "image management systems," were first commercialized in the 1980s. PACS are not yet widespread, since despite the appeal of "one-stop shopping" they still are technically inferior to film in some regards (including some dimensions of image quality). But industry analysts expect the market for PACS to expand to rival the markets for MR and CT scanners in the United States (Medical and Healthcare Marketplace Guide 1995).

A snapshot of the industry

The diagnostic imaging industry has been global—and dominated by giant companies—since its inception. Within months of Wilhelm Roentgen's 1895 discovery of x-rays, both General Electric in the United States and Siemens in Germany were marketing x-ray machines for diagnostic purposes. Since that time, the roster of industry giants has expanded to include Philips (Netherlands), Picker (U.S.-based, but acquired by Britain's General Electric Corporation in 1981), Toshiba (Japan), and Hitachi (Japan). Other companies have come and gone. Small companies have most often been the casualties, but a number of giant corporations in medical supplies, pharmaceuticals, and electronics have made forays into diagnostic imaging, only to later retreat. Examples include Johnson and Johnson, Litton, Pfizer, Raytheon, Searle, SmithKline, Squibb, and Union Carbide.

Table 1 shows the current top ten producers of diagnostic imaging equipment and their shares of the global market, compared with the top ten in 1974. GE, Siemens, Toshiba, Philips, Picker, and Hewlett-Packard, the current top six, were all heavy hitters in 1974 as well. CGR (French) and EMI (British), two top-ten companies from 1974, have been absorbed into GE. Today, the six largest companies produce equipment across the six major imaging modalities. The four smaller companies in the top ten specialize in particular modalities: U.S.-based Acuson, ATL, and Hewlett-Packard excel in ultrasound equipment, and Israel's Elscint specializes in nuclear medicine instruments. U.S.-owned companies still dominate the industry, but there is a substantial showing from other countries, including Siemens (Germany), Philips (Netherlands), Toshiba (Japan), Hitachi (Japan), Picker (U.S.-based, but owned by the General Electric Company of Britain), and Elscint (Israel).

Table 1: Worldwide sales of the ten leading diagnostic imaging companies and total industry sales, millions of current dollars, 1994 and 1974

1994 Top 10 Company	*1994 sales*	*1994 market share*	*1974 Top 10 Company*	*1974 sales*	*1974 market share*
General Electric	1800	24.7%	General Electric	90	22.5%
Siemens	1700	23.3%	Picker	80	20.0%
Hitachi	700	9.6%	Litton Medical	55	13.8%
Toshiba	700	9.6%	Philips	50	12.5%
Picker	490	6.7%	CGR Medical	40	10.0%
Philips	410	5.6%	Siemens	40	10.0%
Hewlett-Packard	260	3.6%	EMI Ltd.	15	3.8%
Acuson	230	3.2%	Toshiba	7	1.8%
ATL	210	2.9%	Hewlett-Packard	5	1.3%
Elscint	180	2.5%	Xonics	5	1.3%
All companies	7300	100.0%		400	100.0%

Source: Medical and Healthcare Marketplace Guide 1975, 1996.

The epochal innovations in the industry—in particular, those resulting in the invention and commercialization of new modalities—have typically been developed by academic researchers and small startup companies. But the industry giants have proven successful fast followers, using their well established marketing, distribution, and service networks and their extensive in-house engineering capacity to enter and in many cases dominate new markets. In addition to designing their own products, the giants have often strengthened their hold on emerging markets (and gained specialized design capabilities) by acquiring smaller companies (Mitchell 1988). General Electric Medical Systems, for instance, absorbed EMI's CT scanner business in 1980, Nicolet XRD in 1984, CGR in 1986, Ultrasonix's ultrasound lines in 1988, and the PET line of Sweden's Scanditronix in 1990 (in addition to setting up a variety of joint ventures in Asia) (Medical and Healthcare Marketplace Guide 1989, 1991). While GEMS has been a particularly avid collector, Siemens acquired Searle's nuclear medicine business in 1981, Oxford Magnet (for MRI equipment) in 1985, and ultrasound company Quantum Med Systems in 1990. Toshiba bought the MRI division of Diasonics in 1989, and Applied Superconetics, Inc., a magnet business, in 1990 (Medical and Healthcare Marketplace Guide 1996).

Unfortunately, tracking the diagnostic imaging industry in standard industrial data sources is no simple matter. Until 1987, the Standard Industrial Classification (SIC) system placed diagnostic imaging equipment in SIC category 3693, "X-ray and electromedical equipment." In addition to diagnostic imaging equipment, this group included machines ranging from electroencephalographs to pacemakers to bronchoscopes. By 1987, diagnostic imaging products amounted to just under half of the value of shipments in this category (U.S. Census Bureau 1990, Table 6a-2). In 1987, SIC 3693 was split into SIC 3844, "X-ray apparatus and tubes and related irradiation apparatus," and 3845, "Electromedical and electrotherapeutic apparatus." Unfortunately for the purposes of analyzing diagnostic imaging, ultrasound and MR scanners, which do not employ ionizing radiation, were grouped in the latter category. In 1987, these two product groups accounted for about one-quarter of the value of shipments in SIC 3845, and one-third of total diagnostic imaging product shipments. As of 1994, ultrasound and MR equipment , still about one-quarter of SIC 3845, had risen to almost half of diagnostic imaging shipments (computed from U.S. International Trade Administration 1995, Table 1508, and U.S. Census Bureau 1995, Table 2). In 1994, diagnostic imaging equipment as a whole accounted for just under one-half of total sales in 3844 and 3845 combined.

Since publicly available Census Bureau data are mostly organized by SIC, the bottom line is that we can only examine government data about diagnostic imaging in combination with other electromedical equipment. Private sector industry analysts have generated far more detailed estimates, but their work resides in the fugitive literature of consultants' reports. Such reports are in general expensive and/or difficult to access, poorly documented, and often inconsistent. The imperfect solution adopted in this paper is to report results by SIC, supplemented by estimates from industry analysts in the limited instances that these were readily available.

Diagnostic imaging equipment is a relatively small industry. In 1994, U.S. diagnostic imaging equipment manufacturers shipped close to $5 billion worth of equipment[3]. Compare this with the other two industries we have studied closely: the machine tool industry shipped a roughly equal amount that year; aircraft engines and engine parts shipped $17 billion. But unlike these other industries, diagnostic imaging has seen near-miraculous growth. In real terms, output has grown more than fourfold since 1970, more than eightfold since 1958. Over this period, the industry has posted average annual compound growth rates of about six percent (in real terms), roughly double that of the U.S. economy as a whole.[4] However, there is reason to believe that the growth boom is over.

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[3] This number totals the output of SIC code 3844 (X-ray apparatus and tubes) plus magnetic resonance imaging equipment and ultrasound scanning devices. Information from U.S. Census Department.

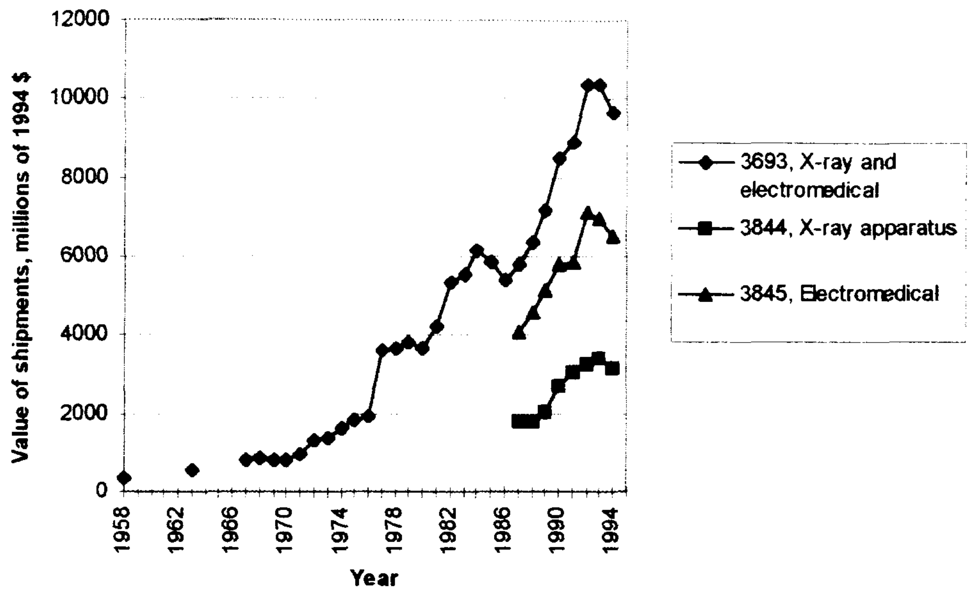
[4] The Producer Price Index for machinery and equipment was used to adjust sales figures for inflation.

From growth to stagnation

Figures 1 and 2 trace the U.S. diagnostic imaging industry's meteoric ascent. Figure 1 shows diagnostic imaging combined with electromedical instruments, whereas Figure 2 offers estimates of diagnostic imaging alone. In its eightfold expansion since 1958, diagnostic imaging has both benefited from and contributed to the upward arc of health care spending in general, which grew sixfold in real terms between 1960 and 1993 (U.S. Department of Commerce 1995, Table 150, deflated by chain-type price index for services). Key to the continued growth in sales was the third party reimbursement system in place in the United States until the 1980s. Between 1940 and 1982, third party payers (insurance companies and government agencies) increased their share of health care expenditures from 15 percent to 75 percent—and 90 percent of hospital expenditures in particular (Foote 1986, 1992). During this time, insurers paid for medical services on nearly a cost-plus basis, giving doctors and hospitals little incentive to contain costs. Though Medicare did not cover most capital costs, there was some pass-through and hospitals could often negotiate sufficiently high reimbursement rates for procedures to recover capital costs. Private insurers tended to follow Medicare in deciding what to cover. Cost-plus reimbursement in health care poses interesting parallels with industries in which the Defense Department has been a major customer, such as machine tools (Forrant 1997) and jet aircraft (Almeida 1997). As with defense contractors in these other industries, there was for a long time little pressure for cost containment, which may have left manufacturers ill prepared for more recent waves of cost-cutting and competitive pressure.

Up to the early 1980s, radiologists and other medical specialists controlled equipment purchases as a professional prerogative and hospital administrators played little role. Since availability of advanced technology is an important factor in a hospital's general prestige and ability to attract top-flight doctors, particularly radiologists, there was little incentive to restrain purchasing (Mitchell 1995, Foote 1992, Steinberg and Cohen 1984, Tomsho 1996).

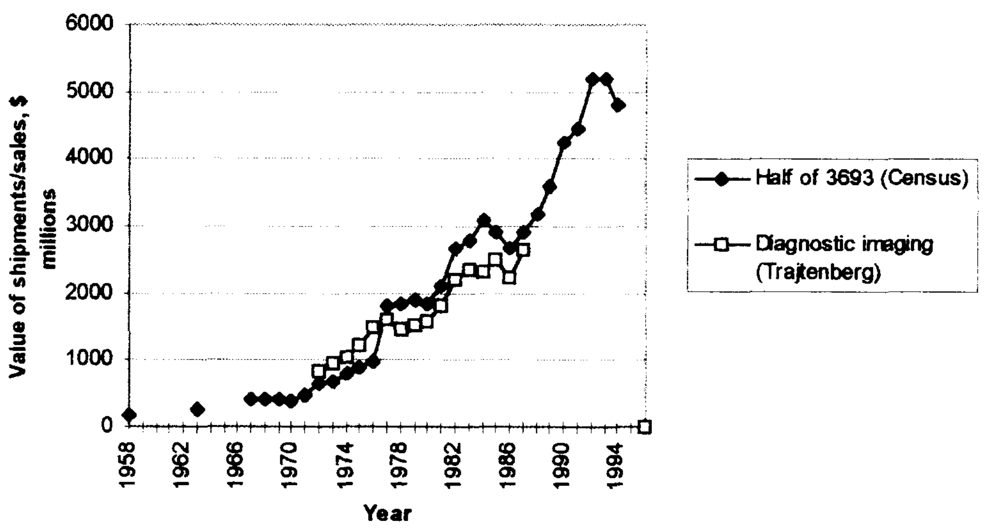
Figure 1: Value of shipments for U.S. diagnostic imaging and electromedical industries in millions of 1994 dollars, 1958-1994



Sources: U.S. Office of Technology Assessment 1984, Table 1; U.S. Census Bureau 1984 (Table 1a), 1990 (Table 1a-2), 1995 (Table 1a). Values adjusted for inflation using Producer Price Index for machinery and equipment.

Note: After 1986, SIC 3693 is continued by the sum of SICs 3844 and 3845.

Figure 2: Sales of U.S. diagnostic imaging industry, approximated from two data sources, 1958-1994



Sources: Sources for SIC 3693 are as in Figure 1. Other series from Trajtenberg 1990, Table 2.1. Values adjusted for inflation using Producer Price Index for machinery and equipment.

As Figures 1 and 2 show, the rise in diagnostic imaging equipment sales has not been unbroken. Rather, periods of rapid growth have alternated with periods of stagnation or even short-term decline. Slowdowns resulted from some combination of restraints on health care spending and lags in equipment innovation. Prior to the last few years, the industry saw three main periods of stagnant sales.

First, in the 1960s, the U.S. market for x-ray equipment temporarily reached saturation. However, the creation of Medicare and Medicaid as part of President Lyndon Johnson's War on Poverty provided a new infusion of cash into health care. The development of CT scanners further revitalized the market in the 1970s.

Second, after nearly doubling in a single year between 1976 and 1977, sales leveled off again in the late 1970s. Producers had overestimated the CT market and overproduced, bringing down prices. Equally important, the U.S. Health Care Financing Administration (HCFA), which handles Medicare reimbursement, imposed a requirement that hospitals seeking to acquire costly equipment must file a Certificate of Need (CON) and obtain approval. Medical diagnostic imaging equipment sales, especially CT, declined briefly. However, while hospitals had to file CON forms, outpatient facilities did not, spurring the growth of outpatient CT imaging facilities affiliated with hospitals or hospital-based radiologists. Since the procedures were still covered by insurance but the facilities did not fall under governmental capital control regulations, the intent of the regulations was effectively undermined. In addition, the appearance of MR machines gave the industry an added boost. Sales began to soar again.

Third, diagnostic imaging equipment sales drooped in 1985-86. The decrease in sales was limited to conventional x-ray equipment, CT scanners, and digital x-ray machines. Once again, a combination of reimbursement jitters and market saturation set in. Digital x-ray equipment did not live up to its technical billing, and its sales were flat for the second half of the 1980s. CT scanners, selling for roughly $1 million per machine, were reaching the limits of demand—especially since MR imagers could offer crisper resolution a similar price. And in 1983 HCFA implemented a prospective payment system for patient treatment. Prospective payment established fixed reimbursement tied to each patient's diagnosis, replacing cost-plus reimbursement with. HCFA is the nation's single largest health care customer, and its regulations are typically adopted by Medicaid and by private insurers as well, so the potential reverberations were enormous. Private insurers, pressed by corporate clients stung by the rising costs of providing health insurance to their employees, followed suit. By 1984 Secretary of Health and Human Services Margaret Heckler claimed that the Reagan administration had "broken the back of the health care inflation monster" (Stein 1986, Reinhardt 1986).

Heckler's boast was premature. Hospitals and doctors' offices soon found ways to at least partially evade the system, and health care industry concerns about cost controls abated somewhat. Diagnostic imaging sales also recovered. MRI purchasing shifted to the now well-established outpatient radiology facilities, and capital costs were accorded lighter treatment under the new system than other hospital costs (Mitchell 1995, Foote 1992, Trajtenberg 1990). MR and conventional x-ray sales enjoyed renewed growth, but ultrasound and nuclear medical equipment, fueled by technical innovations, led the growth spurt.

The continuing difficulty in restraining costs reflected the political and ethical pressures to follow up promising research avenues and to extend available services to the widest possible numbers. The public has an ideal that no one should be denied medical care and that no expense should be spared in delivering the finest care (Foote 1992). Even though the ideal has always been violated regularly in practice, politicians are loath to contradict the ideal too obviously, so it is not surprising that previous cost control plans seem to have been rather porous. Given that CT and MRI represented such dramatic breakthroughs, it is not surprising that the law failed to curb physician and public demand (Foote 1992, Trajtenberg 1990).

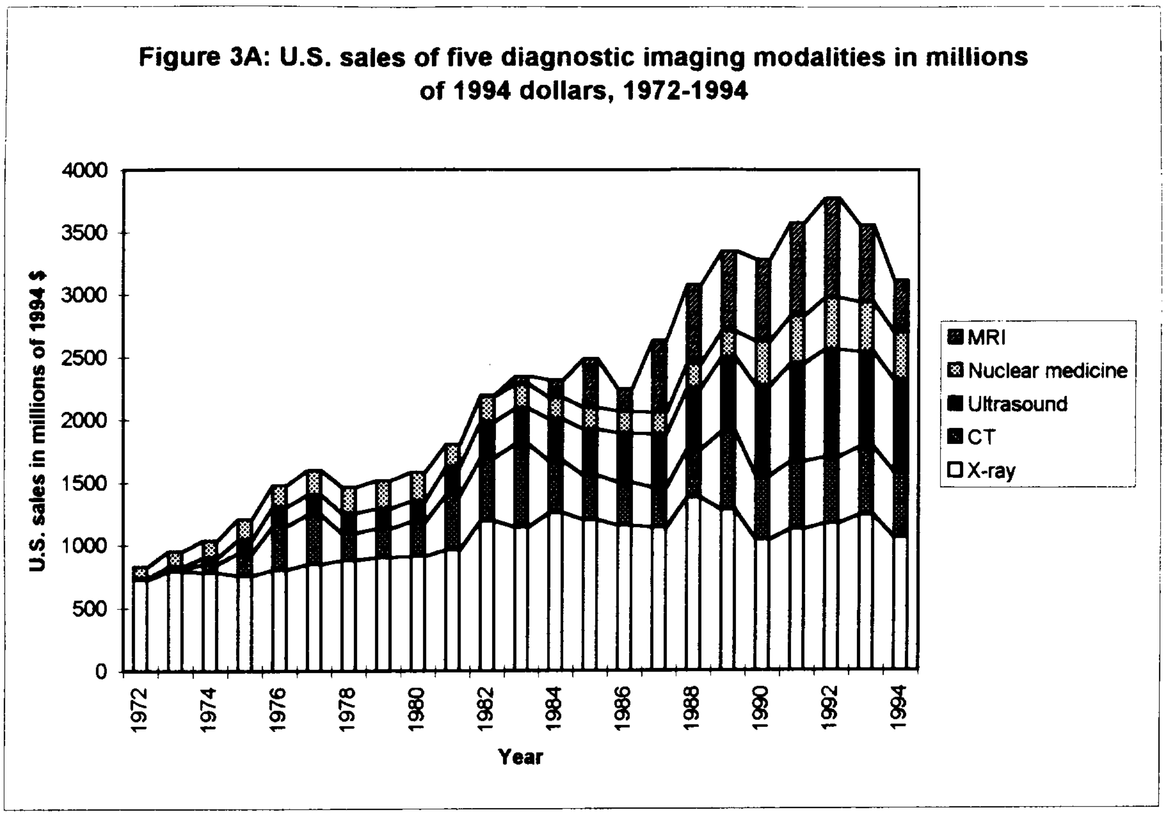
What about the industry's post-1992 slump? This recent flattening of sales reflects sales losses in almost every modality, according to Biomedical Business International (Standard and Poor's 1995). Industry analysts have pointed to overcapacity in a number of modalities, particularly MRI (*Health Industry Today* 10/94, Naj 1994, Standard and Poor's 1995, 1996). Actual or anticipated reimbursement changes have clearly had an impact as well. An obvious explanation for the 1993-94 sputtering of diagnostic imaging equipment sales is the *frisson* due to President Clinton's health care proposal—which was, of course, never enacted. But other changes that attracted far less public attention were at least as important. In 1991, Medicare began to extend prospective payment to hospitals' **equipment**. Whereas earlier Medicare paid hospitals for actual costs minus a 15 percent discount, the new system, phased in over a number of years, pays flat fees based on diagnosis (Standard and Poor's 1992). Moreover, in 1993 new legislation proposed by Congressman Pete Stark of California partially plugged the diagnostic imaging center loophole, by placing limits on physicians' ability to refer patients to imaging centers in which they hold an equity stake (Brean Murray, Foster 1996).

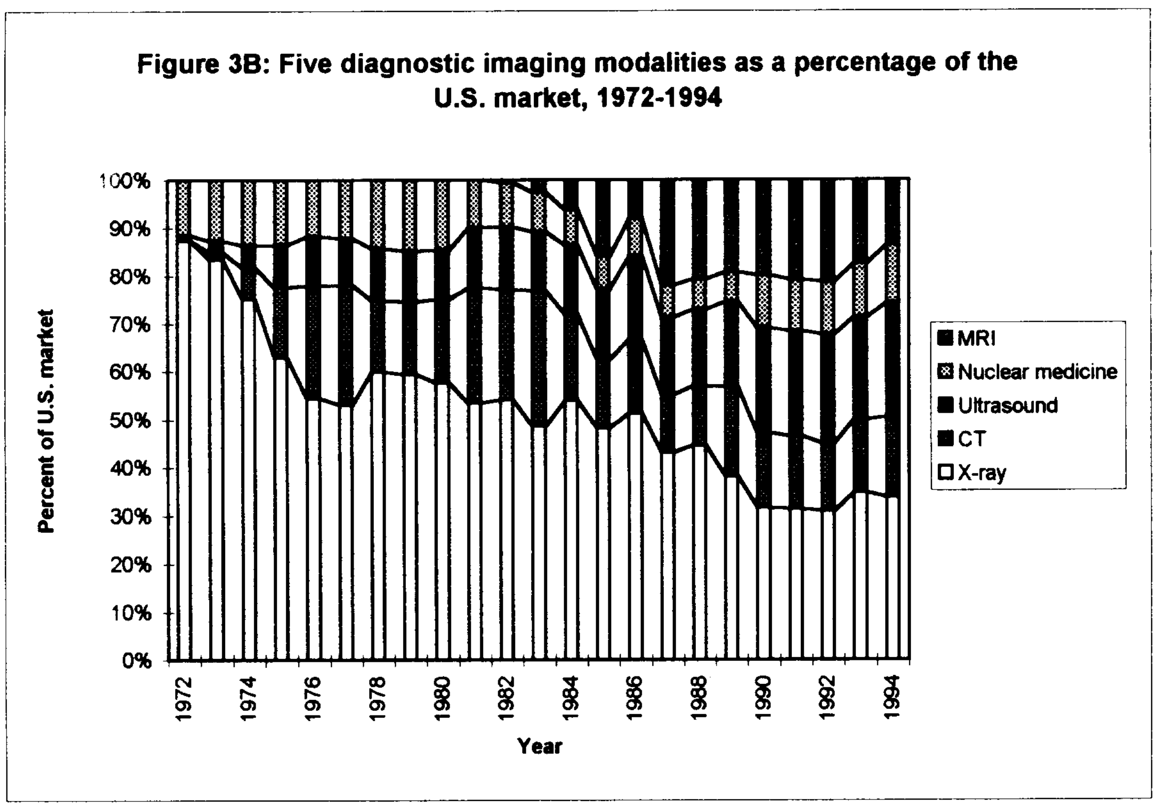
In short, the historical and recent fortunes of the U.S. diagnostic imaging industry have ridden primarily on two factors: the pacing of technological innovations, and the nature of health care financing. Figures 3A-3D trace U.S. and world sales of diagnostic imaging equipment, broken down by modality. Unlike Figures 1 and 2, these graphs depict sales by **all** producers, not just U.S.-based ones. Figures 3A and 3B show **U.S. sales by all producers** in constant dollars, and sales in each modality as percentage of the total. Figures 3C and 3D show the same two series for **world sales** (for which we were not able to obtain as many years of data). The impact of success waves of innovation is clear. CT and ultrasound scanners first made a major splash in 1974, and MRI appeared in 1983. From 90 percent of the U.S. market in 1972, x-ray equipment declined to just above 30 percent in the 1990s. The U.S. market and the broader world market have followed very similar patterns.

[FIGURES 3A-3D ABOUT HERE]

Given the historical pattern driven by technology and third-party reimbursement, should we view the slowdown since 1992 as another temporary halt, or a long-term plateau? Assuredly, it would be unwise to predict an end to innovation in diagnostic imaging. But most innovation in the field has had a moderately long incubation period. For example, ten years passed from the construction of the first nuclear medicine machine to the creation of a marketable product; the CT scanner took five years from invention to commercialization (Mitchell 1988). Despite some analysts' excitement over emerging advances in MRI (Standard and Poor's 1997), in our view the only innovation currently visible on the horizon that seems likely to have an impact similar in scale to the appearance of a new modality is the PACS.

As for reimbursement, the federal government continues to clamp down bit by bit on health care costs, including equipment costs. But even if government's success in containing health care costs remains limited, the spread of health maintenance organizations (HMOs) and managed care in the **private** sector has begun to significantly squeeze reimbursement rates.





Note: X-ray and CT sales imputed, 1988-89.

Sources: 1972-87 from Trajtenberg 1990; 1988-89 from National Electrical Manufacturers Assoc., reported in Standard & Poor's, 1992; 199094 from Frost & Sullivan, reported in Standard & Poor's 1995

Figure 3C: World sales of five diagnostic imaging modalities in millions of 1994 dollars, selected years 1974-1996

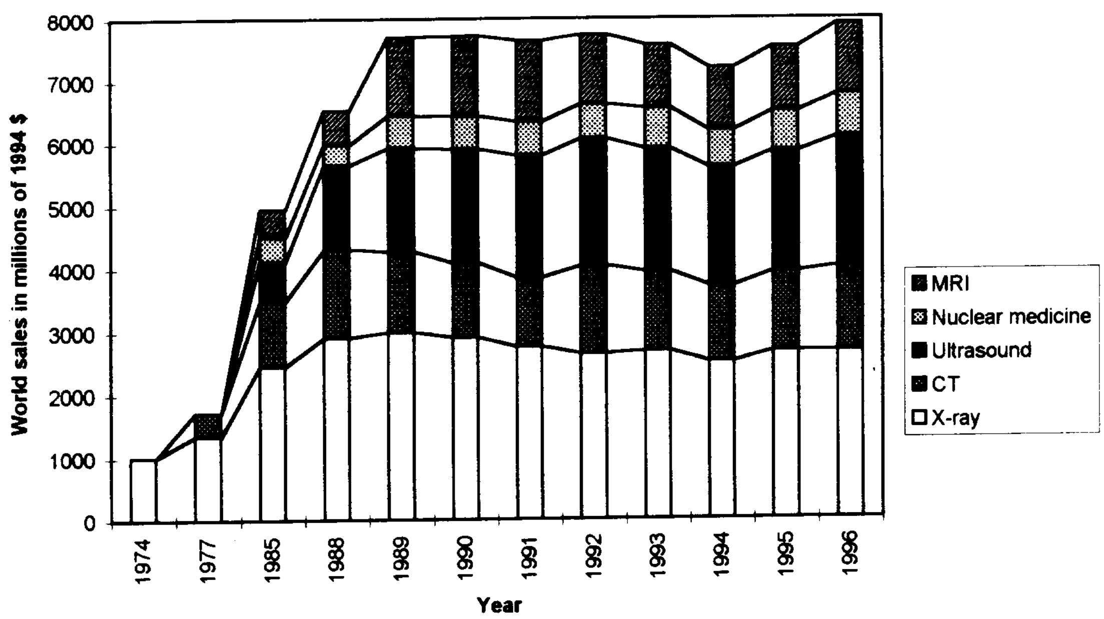
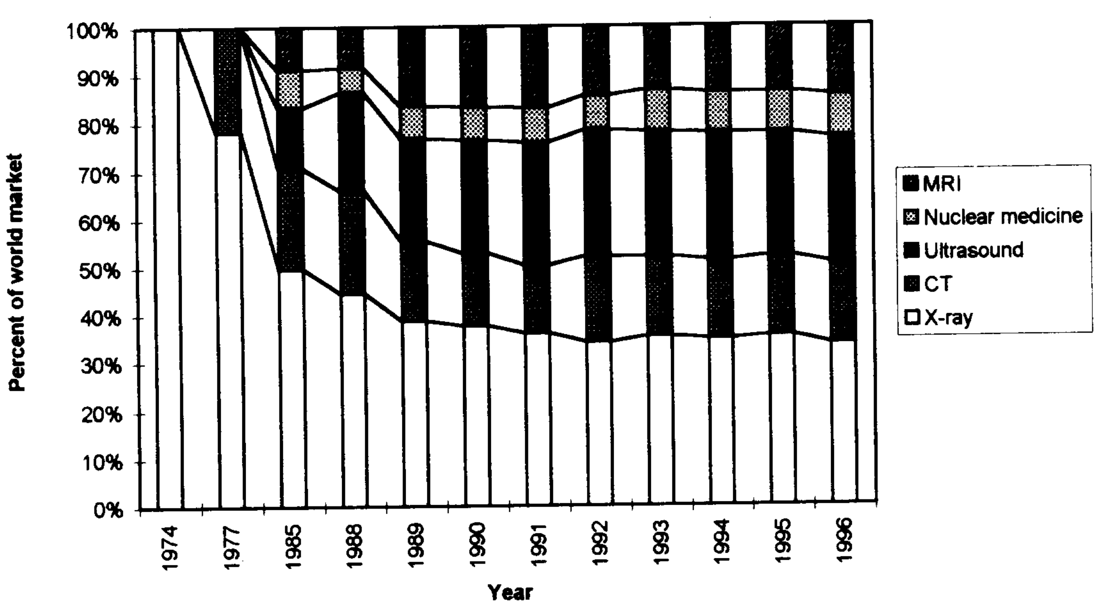


Figure 3D: Five diagnostic imaging modalities as a percentage of the world market, selected years 1974-1996



Note: CT combined with X-ray in 1974. X-ray interpolated, 1985 and 1988. 1995 estimated, 1996 forecast.
Source: Medical and Healthcare Marketplace Guide, publishers variously International Bio-Medical Information Service (1974-1988), MLR Biomedical Information Services (1989-1990), IDD Enterprises (1991-1996).

Between 1986 and 1996, HMOs spread from 10 percent to 30 percent of the insured population (Pham 1997), and they have become much more aggressive in limiting payments to providers.

The effects of this latest wave of cost containment are profound, and appear likely to deepen further in coming years. For diagnostic imaging equipment in particular, the implications are grave. In addition to the direct impact of managed care, purchaser uncertainty has escalated. One response by health care providers has been to turn to the market for second-hand and reconditioned equipment. Large hospital chains are now buying refurbished systems, which previously were only marketed to rural and Third World buyers. GE markets its own used equipment; other companies such as Picker are offering to overhaul machines from other companies, as well as their own. Used MRIs can cost $.85-$1.1 million, rather than $1.5-$2 million, used CT scanners can cost $245-470,000, rather than $700-850,000 (Scott 1995, Tomsho 1996). "This was a market where you bought something new, you bought the bells and whistles, and you replaced it every five years," commented Robert McGee, president of Serviscope Corp., an equipment-services company in Wallingford, Connecticut. "Now it's more like the airline industry. With proper maintenance and proper upgrades, equipment does not need to be replaced every five years unless there is some clinical reason (Scott 1995). Smaller hospitals are starting to contract with mobile MRI units that make regular visits (*Health Industry Today*, 10/94). And hospitals are also simply deferring replacement of diagnostic imaging equipment (Lehman Brothers 1996, Standard and Poor's 1997).

With breakneck rates of equipment acquisition through most of the 1980s followed by stringent cost pressures in the 1990s, the current market appears to be saturated. Though our time series for U.S. output and demand extend only to 1994 (Figures 1, 3A-B), a Picker executive reported that the market for diagnostic imaging products declined 25 percent in the following two years (1994-1996) (*IW*, 5/6/96). General Electric Medical Systems, the industry leader, announced a restructuring plan in 1993 in response to the downturn (*Health Industry Today*, 7/93), and Hewlett-Packard followed suit a few years later (Hewlett-Packard web site, 1996). ***

But in addition to innovation and reimbursement, a third factor will prove increasingly important: international markets. While U.S. imaging equipment sales—which currently account for about 40 percent of sales world-wide—may be leveling off, world sales are poised to take off. Already, between 1989 and 1994, exports climbed from 32 percent to 39 percent of x-ray and electromedical shipments by U.S. producers (U.S. International Trade Administration 1995). Consultants Frost and Sullivan projected a near-doubling of the world market between 1993 and 2000 (Standard and Poor's 1994). Most of this growth will not take place in Western Europe or Japan, since, as in the United States, the markets of these countries are relatively saturated (and the national health systems of Western Europe have placed strict controls on new equipment purchases). Instead, rapid demand growth is likely in Asia, Latin America, and Eastern Europe. For instance, between 1991 and 1993, U.S. exports to China of diagnostic ultrasound equipment more than doubled; exports of MRI machines increased a staggering fourteen-fold (Chan 1994a). And for overall growth in imports of U.S.-made medical equipment, China is actually at the **low** end among Asian countries (Chan 1994b). The key question, then, is to what extent U.S. producers are well positioned to maintain and expand their world market share. We will return to this question below.

2) Outsourcing and downsizing by U.S. diagnostic imaging equipment producers

As cost reduction pressures gradually mounted from the late 1970s onward, diagnostic imaging equipment manufacturers responded with a variety of strategies. As of the early 1980s, most U.S. manufacturers still voiced the view that price would not be a significant determinant of market share as non-price competition (based on image quality, product features, reliability, service) would dominate (Steinberg and Cohen 1984). But by the 1990s, efforts to reduce purchasing prices were in full swing. Such efforts included a variety of design changes. But U.S. producers also sought to reduce production costs by drawing on a by now familiar repertoire of tools of corporate restructuring, including outsourcing and downsizing.

Design-based cost reduction strategies have taken several forms:

- Scale down equipment. Less powerful and versatile machines have long been the standard in Asia, but United States (and to a lesser extent European) producers historically have targeted a premium market. This is starting to change. By selectively removing less needed or non-reimbursed functions from the equipment, Siemens lowered the price of its Magnetom Open MRI to $1 million. U.S. manufacturers are now trying to market mid and low end MRI systems to first-time buyers and imaging facilities that need backup systems. Many of these are designed only to scan specific sites and deliver lower quality whole-body images. Still, smaller systems require less space and installation costs, which can be important considerations. Philips has managed to reduce the size of its high-end system so that it weighs only 8,000 pounds, compared to 12,000 pounds for a comparable GE model (*Health Industry Today*, 10/94). But GE Medical Systems (GEMS) and other companies have also introduced low- and mid-range models of MR and CT scanners (Morone 1993).

- Design machines to increase throughput of patients. Fonar introduced an MRI that can scan four people in quick succession. Philips introduced an x-ray machine that can pivot between two rooms, reducing idle time (Naj 1994).

- Market high-end machines as a way to reduce other costs. GE is developing an MRI that would give surgeons real-time 3-D images as they guide surgical instruments through small incisions, allowing them to avoid nerves, blood vessels, and organs. This less invasive form of surgery would save money by minimizing risk of complications and long hospital stays (Naj 1994; *Health Industry Today*, 10/94). Producers are working on a number of other, less ambitious multi-purpose machines and enhancements to image quality to pursue a value added strategy, rather than going an economy route (*Health Industry Today*, 9/95, p.9; *Health Industry Today*, 5/95, p.11). Moreover, manufacturers are promoting picture archiving communications systems (PACS) as a way to cut down on diagnostic imaging costs themselves (*IW* 5/96). One hospital using a Fuji PACS that replaces film with computer storage reports savings of $100,000 per year.

- Enhance the capabilities of the less expensive modalities, so that they can perform functions that currently require more costly equipment. Some believe that improvements in ultrasound imaging, including future development of real-time 3-D imaging, will pose a challenge to CT and MRI, since ultrasound systems are a fraction of the cost of the other two (*Health Industry Today*, July 1994).

Of course, the 1980s and 1990s were also a time when U.S. corporations in general, and manufacturers in particular, were using outsourcing, delayering, and downsizing to shrink workforces and drive down production costs (Harrison 1994). Thus, it is not surprising that restructuring aimed at increasing efficiency diffused among U.S. diagnostic imaging producers.

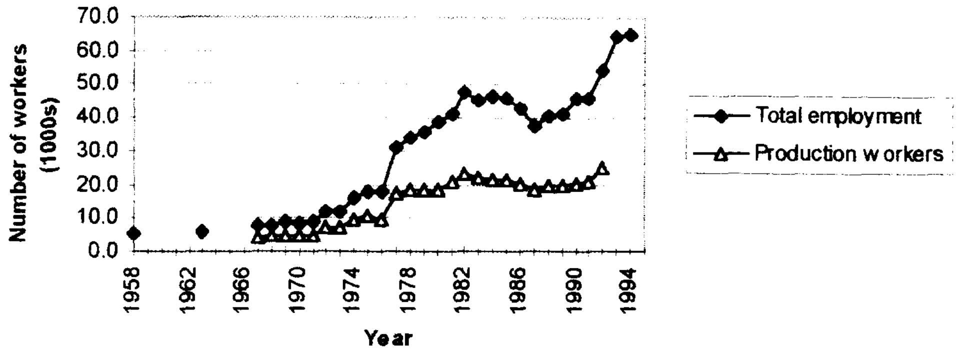
The two U.S.-based imaging equipment manufacturers under study by the author and others took two different approaches to outsourcing. One of the two companies—call it Company A—moved strongly toward sourcing components from outside suppliers. Beginning in the late 1980s and continuing into the 1990s, Company A outsourced thousands of parts, and laid off about almost 40 percent of its production workforce. Company A began to outsource some design work as well, reducing the size of its engineering workforce. Company B, on the other hand, has not outsourced components to anything like the same extent. Instead, Company B has outsourced **workers**, by using temporary agency workers to staff about one-quarter of its manufacturing positions.

One indicator of outsourcing is the growing share of value of U.S. x-ray equipment shipments that is accounted for by parts and accessories, rather than finished equipment. The share of parts and accessories (excluding tubes, which the industry giants continue to produce themselves) rose from seven percent in 1982 to eleven percent in 1987 (U.S. Census Bureau 1984, 1990). (Unfortunately, published 1992 Census of Manufactures reports did not include the relevant information.)

Outsourcing also offers one possible interpretation of broader industry employment and output trends. After 1977, total employment in the x-ray and electromedical industries more than doubled, but the production workforce remained essentially unchanged (Figure 4). From a peak of 61 percent of the industry workforce in the early 1970s, production workers had tumbled to 46 percent by twenty years later. Inflation-corrected value added per employee, marched steadily upward from $60,000 in 1967 to $123,000 in 1992 (in 1994 dollars), with the most rapid increase taking place during the 1980s.

A number of possible explanations are consistent with the employment pattern. In addition to outsourcing, it could (and almost surely does, in part) result from automation, offshore production, or simply the increasingly technical nature of the industry. Our limited case study evidence suggests that outsourcing interacts with these other processes. For example, outsourcing **reinforces** the shift to a more technical workforce. In Company A, the shop floor of twenty years ago swarmed with machine operators, machinists, and semi-skilled assemblers, building equipment more or less from scratch. Today, a much smaller number of workers assemble and test sub-assemblies. Since testing is such a large part of the job, most have at least some technical training. The net result is more high-quality jobs, but **fewer** high-quality jobs for people without higher education. Shop floor testing and technical jobs typically require at least some community college, and engineering jobs require at least a four year degree.

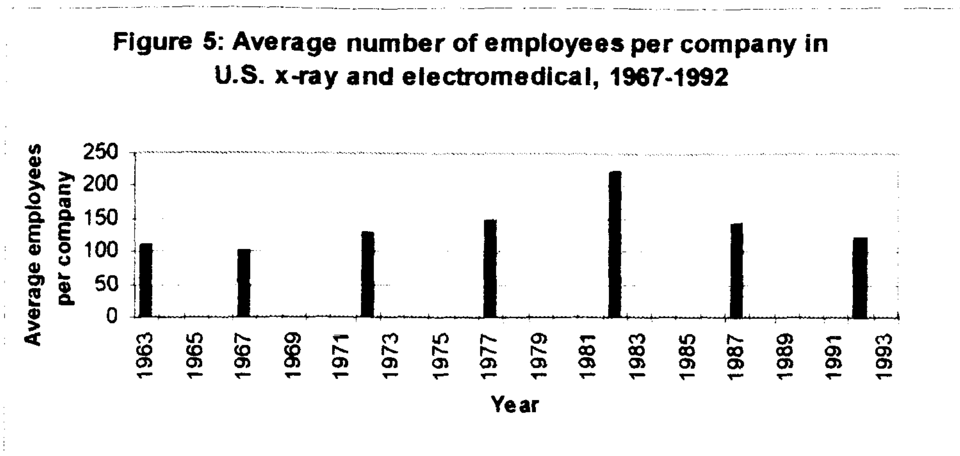
Figure 4: Total employment and production workers in U.S. x-ray and electromedical industries, thousands, 1958-94



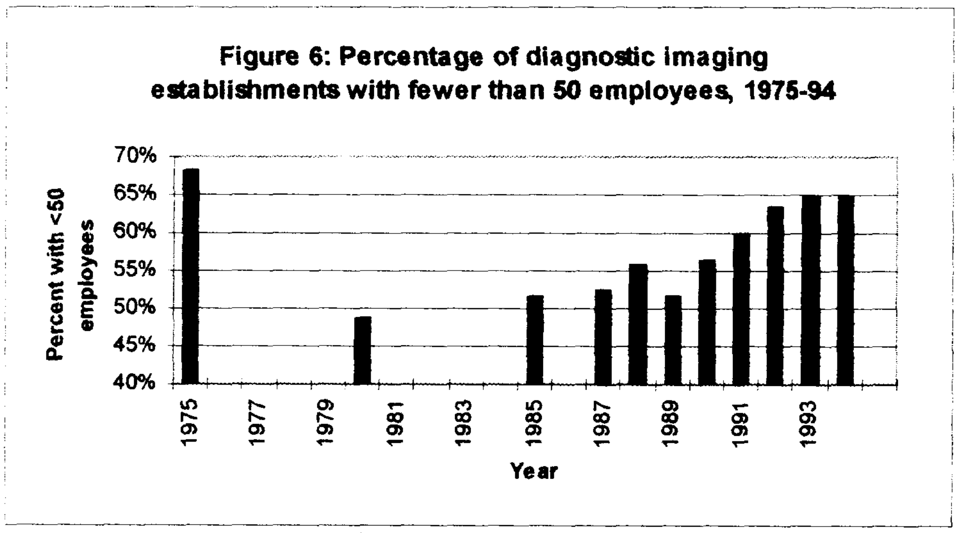
Sources: U.S. Office of Technology Assessment 1984, Table 4; U.S. Census Bureau 1984 (Table 1a), 1990 (Table 1a-2), 1995 (Table 1a). Total employment in 1993 and 1994 imputed from *County Business Patterns (United States)*, 1993 and 1994, Table 1b.

Some outsourcing—for example, purchases of circuit boards, metal cabinets, or computer monitors—shifts production outside the diagnostic imaging industry altogether. But for accounting purposes, production of diagnostic imaging-specific subassemblies stays **within** the diagnostic imaging industry, simply shifting production to smaller companies. This would lead us to expect smaller firm sizes in the industry.

Observed changes in firm size are consistent with this expectation, though other explanations are also possible. Tables 5 and 6 display the changes. Firm sizes grew from the late 1960s to the early 1980s, boosting the number of employees per company (Figure 5) and reducing the proportion of total industry employment in small establishments (Figure 6). From the early 1980s onward, the direction reversed and firm sizes diminished. The numbers appear to reflect a history in which first larger companies grew their workforces by acquiring smaller companies and expanding market share, and then with outsourcing in the 1980s, the process reversed: the large companies shrank, and a growing fringe of small companies emerged to supply sub-assemblies. However, the downturn in firm size could also simply reflect entry of small competitors, rather than suppliers. More definitive explanations of industry changes in employment and firm size await additional case study research.



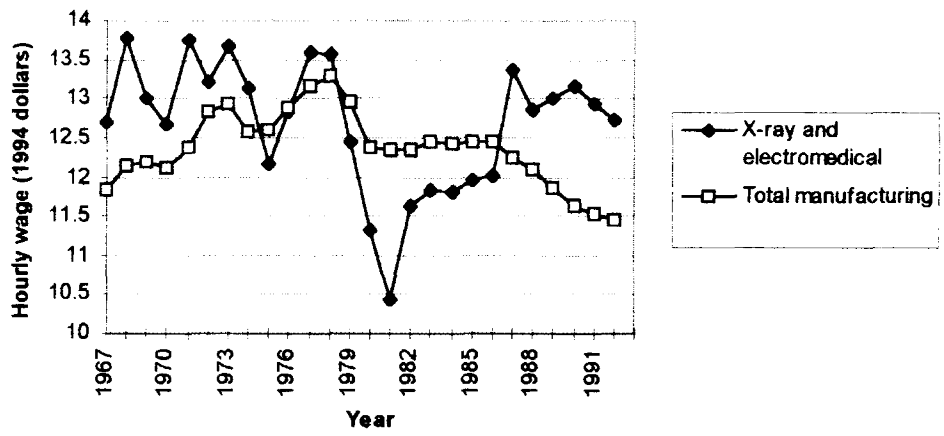
Sources: Calculated by authors from U.S. Office of Technology Assessment 1984, Tables 4 and 13; U.S. Census Bureau 1984 (Table 1a), 1990 (Table 1a-2), 1995 (Table 1a).



Source: U.S. Department of Commerce, *County Business Patterns*, various years, Table 1b.

The effect of outsourcing and firm size changes on production workers' wages has been ambiguous. Figure 7 tracks these wages over time. Production workers' wages in the x-ray and electromedical industry are considerably more volatile than average manufacturing wages, since they are affected greatly by a few union contracts and the fates of a few companies. Their wages dove in 1980-81 recession, but they managed to work their way out of that hole as the economy expanded once more. (The 1980-81 wage decline probably is due at least in part to compositional changes—such as greater layoffs of high-paid than of low-paid workers—rather than simply a drop in the wages paid to individuals.) The real story is not that sudden drop, but rather the long-term stagnation of wages, which fluctuated around $13.50 an hour (in 1994 dollars) as of the early 1970s, and around $13.00 an hour in the late 1980s and early 1990s. Stagnation, of course, was also the fate of U.S. manufacturing wages in general, and indeed U.S. wages in general. Over the 1970s and 1980s, U.S. workers lost ground relative to their counterparts in Europe and Japan (Freeman 1994, Table 1.2). Compared to manufacturing workers as a group, production workers in x-ray and electromedical equipment have done relatively well. Meanwhile, the real hourly wages of non-production (professional, technical, and managerial) workers in the industry, which had hovered between $19 and $21 from 1967 and 1982, climbed to $25 between 1982 and 1992 (not shown; U.S. Census Bureau 1984, 1990, 1995; all figures in 1994 dollars; calculations assume these employees worked 40 hours per week).

Figure 7: Hourly wages of production workers (1994 dollars) in U.S. x-ray and electromedical and all anufacturing, 1967-1992



Source: Computed by authors from U.S. Census Bureau 1984 (Table 1a), 1990 (Table 1a-2), 1995 (Table 1a).

What, if anything, can we conclude about the impact of outsourcing on production worker wages? Unfortunately, we cannot conclude much. Based on available data, we do not have a reliable way to distinguish between supplying and purchasing companies within the diagnostic imaging industry, and we have no way of knowing what businesses outside of the industry are its suppliers. Within x-ray and electromedical manufacturing, smaller businesses do tend to pay lower average wages (establishments employing 500 to 999 employees pay the average employees 25 percent more per year than those with 10 to 19 employees [computed by authors from *County Business Patterns*, 1994, Table 1b]). But data on wages by firm size combine production and non-production workers, so this wage gap may just result from higher proportions of (highly paid) non-production workers at larger companies. Looking at wage change within the industry over time, we see that during the period of outsourcing, production worker wages within x-ray and electromedical were **climbing** from their early 1980s low, and pulling ahead of the manufacturing average, though they have not yet re-attained their 1970s peak. This would be expected if low-end production work was being shed, but the unanswered question is who was now performing this low-end work, and at what wages. Reaching conclusions about the wage effects of outsourcing will require additional case study work.

Downsizing and outsourcing affect managers and engineers as well as production workers. The stated purposes of restructuring are to allow companies to focus on their core competencies, and to outsource where other producers can do the job better or at lower cost.

"Our goal is to be competitive," commented one top Company A manager. "That means everything is on the table." However, some managers interviewed at companies A and B expressed the fear that excessive outsourcing and downsizing may harm the long-run competitive strength of their respective companies. At Company A, managers complained that excessive outsourcing has resulted in quality problems. "Quality is a continual struggle," commented one manager. "It is clear why: we expect a lot and don't want to pay much. The supplier base is under pressure to give on the price to get in the game." Some also worry that outsourcing results in the loss of in-house engineering competencies: "We're just outsourcing and outsourcing and outsourcing. We used to have a lot of knowledge about the products. Once you outsource, you lose the competencies."

A number of Company A managers commented that repeated rounds of downsizing and escalating performance goals had exhausted the remaining management and engineering workforce. "The business is... in the red zone on the tachometer," commented one. He added that a certain amount of redundancy and slack is necessary to allow room for organizational memory and learning. These concerns about organizational learning offer some support for Lazonick and O'Sullivan's (1996) hypothesis that insufficient organizational integration of various layers of the workforce has weakened the competitive advantage of U.S. manufacturers.

Company B has made far more strenuous efforts to retain its workforce, keeping company-wide turnover among permanent employees down around five percent. But part of their formula for doing so has been to buffer long-term employees with a ring of temporary agency workers. This strategy brings its own contradictions. One Company B manager commented on tension between regular and contract employees. She added, "It may not be such a good idea to have contract employees. You want to have people you can count on"—given quality goals and extensive training requirements.

Have outsourcing and downsizing actually weakened the competitiveness of U.S.-based diagnostic imaging companies? To begin to answer that question, let us examine the U.S. industry in international context.

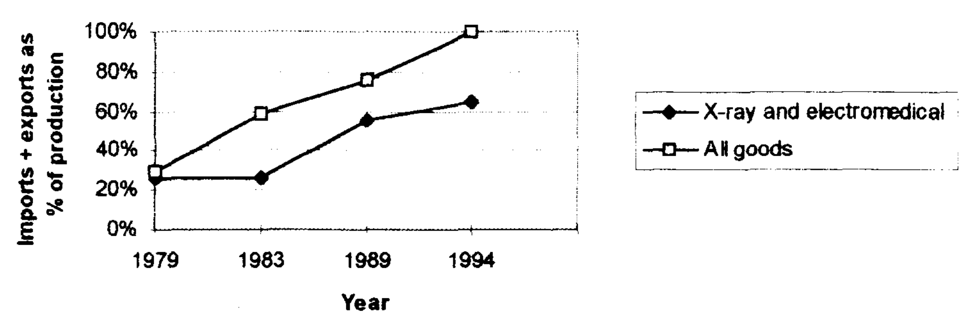
3) Globalization and the rise of Japanese producers

As we commented earlier, diagnostic imaging was born as an international industry. General Electric and Siemens were both present at the creation of commercial x-ray machines in 1896. As of 1958, the U.S. diagnostic imaging market was dominated by these two, along with U.S.-based Picker and Westinghouse, and the Dutch company Philips. Together the five companies controlled 70 to 75 percent of the American market. Thirty years later in 1988, GE, Siemens, Picker (now owned by the British GEC), and Philips controlled 70 percent of the U.S. market; only Westinghouse had dropped out (Mitchell 1988).

Despite this apparent stability among industry leaders, globalization has in fact increased markedly. Consider two indices of globalization. First, Figure 8 tracks the ratio of imports plus exports to U.S. domestic production, for the x-ray and electromedical industry and for all goods. This index computes a ratio of global production and consumption to domestic production. (Note that this index can exceed 100 percent, since only **exports**, not imports, are a subset of domestic production.) Diagnostic imaging has not kept up with the blistering pace of globalization for all goods—which saw this ratio more than triple between 1979 and 1994.

Nonetheless, globalization in x-ray and electromedical products also surged, more than doubling over the same period.

Figure 8: Sum of imports and exports as a percentage of U.S. domestic production, x-ray/electromedical and all goods, 1979-1994



Sources: U.S. Office of Technology Assessment, 1984, Table 18, and U.S. International Trade Administration, 1995, Table 1508.

Second, Table 2 shows the breakdown of diagnostic imaging equipment sold in the United States by **nationality of ownership** of the company. Between 1958 and 1994, sales by U.S.-owned companies tumbled from three-quarters of total equipment sales to just over one-third, with the difference going roughly equally split between European and Japanese companies. However, this table does not accurately reflect changes in the location of **production**. Most of the rise in the European share results from the purchase of U.S. companies by European ones. Most notable among these purchases was the 1981 acquisition of Picker by GEC. However, Philips and Siemens also absorbed U.S. producers: for example, Philips purchased Rohe Scientific, the ultrasound company that perfected the gray scale technology, in 1976; Siemens acquired American producers of equipment for ultrasound (Searle) and nuclear medicine (Quantum) producers (Friar 1986, Mitchell 1988). Thus, the rising European share largely tracks continuing U.S.-based production under new ownership. (For that matter, U.S. companies have also acquired European ones, as when GE Medical Systems absorbed France's Thomson-CGR in 1987.) On the other hand, the sextupled Japanese share understates the growing portion of production taking place in Japan, since, as will be discussed further below, Japanese companies produce increasing amounts of equipment sold by U.S.-owned businesses.

Table 2: Percentage of diagnostic imaging equipment sales in the United States, by nationality of ownership of company, 1958, 1986, and 1994

Nationality of ownership	*1958*	*1986*	*1994*
United States	75%	45%	37%
Europe	20%	45%	39%
Japan	3%	6%	21%
Other	2%	4%	3%

Note: 1994 just gives percentage of sales within top 10 companies (which accounted for 91 percent of industry sales)
Sources: Mitchell 1988, Figure 8-4; Medical and Healthcare Marketplace Guide 1996, p.223.

Table 3 shows imports, exports, and trade balances for the U.S. x-ray and electromedical industry. It is difficult to discern any long term trend. However, between 1989 and 1994 (though the years in between are not shown in the table), the U.S. x-ray industry has consistently run a trade deficit, whereas the U.S. electromedical industry has consistently posted a somewhat larger trade surplus.

Table 3: Imports, exports, and trade balances in U.S. diagnostic imaging In 1994 dollars, 1979-1994

	1979	*1983*	*1989*	*1994*
X-RAY AND ELECTROMEDICAL				
Value of imports (millions of 1994 dollars)	449	816	1978	2439
Value of exports (millions of 1994 dollars)	1169	1297	2277	3807
Trade balance (millions of 1994 dollars)	721	481	299	1368
X-RAY APPARATUS (SIC 3844)				
Value of imports (millions of 1994 dollars)			936	1131
Value of exports (millions of 1994 dollars)			562	987
Trade balance (millions of 1994 dollars)			-374	-144
ELECTROMEDICAL (SIC 3845)				
Value of imports (millions of 1994 dollars)			1042	1308
Value of exports (millions of 1994 dollars)			1716	2820
Trade balance (millions of 1994 dollars)			673	1512

Sources: U.S. Office of Technology Assessment, 1984, Table 18, and U.S. International Trade Administration, 1995, Table 1508.

How are these deficits and surpluses distributed across trading partners? As Table 4 demonstrates, the largest source of imports **and** exports of diagnostic imaging and related equipment is the 15-member European Community. Second is an east Asian market consisting of Japan and the nearby newly industrializing countries (NICs) of Taiwan, Hong Kong, Korea, and Singapore. In x-ray equipment, the United States runs substantial trade deficits with Europe and Japan. (60 percent of the trade imbalance with Europe results from exchange with Germany, and most of the rest from trade with the Netherlands—pointing to the importance of Siemens and Philips in the U.S. market.) In electromedical equipment, the category that includes MRI and ultrasound scanners, the United States is a net exporter to Europe, but a net importer from Japan. Adding the two industry categories together yields a trade deficit of $24 million with Europe, and a deficit of $297 million with Japan.

Also noteworthy is the high level of cross-trade—exports **and** imports of equipment to/from the same region. This points to the need to understand which companies and countries are dominating which activities within the diagnostic imaging equipment industry, which we cannot determine from these aggregate data. Such detailed information could tell us a great deal about the loci of learning and sustained competitive advantage across companies and nations.

Table 4: U.S. trade in diagnostic imaging equipment by partner, 1992
In millions of 1992 dollars

	X-ray apparatus and tubes (SIC 3844)					*Electromedical equipment (SIC 3845)*				
Region	**Exports**		**Imports**		**Surplus/**	**Exports**		**Imports**		**Surplus/**
	Value	**Share**	**Value**	**Share**	**Deficit**	**Value**	**Share**	**Value**	**Share**	**Deficit**
Canada, Mexico	118	14.9	65	5.6	53	247	10.9	127	5.6	120
European Community	284	35.9	814	70.5	-530	991	44.0	485	38.0	506
Japan	120	15.2	218	18.9	-98	298	13.2	497	38.9	-199
East Asia NICs	81	10.3	4	0.3	77	242	10.7	80	6.2	162
South America	70	8.8	0	0.0	70	89	4.0	0	0.0	89
Other	118	14.9	53	4.6	65	389	17.2	88	6.9	301
Total	791	100	1155	100	-364	2255	100	1277	100	978

Source: U.S. International Trade Administration 1995.

Even without additional details, these trade figures focus attention on Japan. Japanese companies participating in the U.S. diagnostic imaging market include Toshiba and Hitachi, but also "Shimadzu, JEOL, Mitsubishi, Matsushita, Aloka and at least 15 others" (Mitchell 1988, p.8.4). As Mitchell (1988) describes, Japan-based production has become increasingly important in the U.S. market in four ways:

a) Supply of components—a role played by Japanese firms since the 1950s.

b) Supply of systems to be sold under U.S. and European companies' labels. Japanese companies have sold systems under these terms since the late 1960s. In some niche markets the Japanese presence is sizable: for instance, the Acoma X-Ray Industry Company, Ltd. produced one-quarter of all x-ray mammography systems sold in the United States in the late 1980s—all of which were marketed under U.S. and European labels.

c) Direct and indirect distribution of Japanese companies' branded products. Toshiba was the first Japanese company to set up its own sales force in the United States in 1976, but other companies have since followed suit.

d) Joint ventures between Japanese and U.S. or European companies. General Electric formed the Tokyo-based Yokogawa Medical Systems (YMS) joint venture with Yokogawa Electrical Works in 1981 (Tichy and Sherman 1994). According to Mitchell (1988, p.8.5), YMS (now GEYMS) manufactures most of GE's ultrasound products, much of its CT product line, and some MR products as well. (GE also has joint ventures and subsidiaries in

China, India, Korea, and Vietnam.) Picker created a joint venture with Toray Industries and Fuji Electric Company, and that joint venture now produces most of Picker's ultrasound and nuclear medicine equipment. Siemens, as well, has launched a joint venture with Asahi in the late 1980s. The reverse phenomenon has also occurred—for example, Toshiba acquired the MRI division of U.S.-based Diasonics in 1989 after selling Diasonics machines under its label for a number of years—but is far less common (Medical and Healthcare Marketplace Guide 1996).

Beyond the particular forms by which Japanese producers have expanded production, it is important to note that these companies have also gradually widened the range of modalities in which they produce, and have expanded their product lines both up- and downmarket.

Preliminary visits to three Japanese diagnostic imaging companies revealed significant differences in the organization of production, relative to U.S.-based companies. Among them were:

- A higher degree of vertical integration of production, despite substantial recent movement in the direction of outsourcing. One Company A manager, while describing his company's outsourcing, noted that "The Japanese are the antithesis of this—they make everything." The Japanese managers, on the other hand, reported high levels of outsourcing by their standards. It will require additional case study work to adequately compare the degree of vertical disintegration in the two settings.
- Closer, longer-term, more consultative relationships with suppliers.
- Standard Japanese practices of lifetime employment, substantial on-the-job training, and opportunities for production worker input into management decision-making.

Engineering managers in one company expressed low opinions of Japanese companies' capacity for innovation. But Mitchell (1988) warns against dismissing the Japanese diagnostic imaging industry as imitative, noting that many Japanese companies have strong in-house capacity, and that technology transfer has flowed from Japan as well as to it. Japanese academic researchers began studying x-rays in 1898, only a few years after their European and U.S. counterparts. Shimadzu began commercial manufacture of x-ray machines in 1911, followed shortly thereafter by Toshiba. Japanese diagnostic imaging equipment manufacturers, like Japanese manufacturers in other products, have a reputation for high quality and extremely efficient production processes. From available evidence, it is not clear what is the relative importance of quality, price, and innovation in explaining the inroads gained by Japanese manufacturers.

Other Asian companies have more recently begun following the lead of Japanese imaging equipment manufacturers. For example, Medison, the first manufacturer of diagnostic ultrasound equipment in South Korea, saw sales rocket up at 60 percent per year between 1986 and 1995, fueled by the Korean government's drive to modernize its health care system (Dongsuh Securities 1996). Meanwhile, General Electric and Philips have also entered the Korean imaging equipment market through joint ventures (with Samsung, in the case of GE). And China's booming market for diagnostic imaging equipment is served by joint ventures established by GE, Siemens, Toshiba, Hitachi, Hewlett-Packard, and numerous others (Chan 1994a).

Despite the growing Japanese and other Asian presence in diagnostic imaging, we certainly cannot flatly assert that U.S. companies are losing the competitive battle. The U.S. trade balance in x-ray and electromedical equipment remains positive and in fact rather large. GEMS, which held a 22.5 percent market share in 1974, continues to lead the market with a 24.7 percent share in 1994 (though of course the latter number includes GE's Asian and European joint ventures and subsidiaries). However, second-tier U.S. producers have lost ground. The five U.S. companies among the top ten producers in 1974 accounted for 60 percent of global sales; the five U.S. top-ten companies in 1994 account for 41 percent. (This counts Picker as a U.S. company both times despite its intervening acquisition by a British multinational. If we exclude Picker in 1994, the U.S. share drops to 34 percent of total industry sales; as Table 2 shows, this is 37 percent of top-ten company sales.) Meanwhile, Japanese top-ten companies' share of total industry sales expanded from two percent in 1974 to 19 percent in 1994. It would require more detailed case study analysis to determine the extent to which U.S. dominance is likely to continue to erode.

4) Organizational integration in U.S. diagnostic imaging companies

Lazonick and O'Sullivan (1996) define **organizational integration** as the integration of productive actors into a business organization's learning and decision-making activities. They argue that though U.S. manufacturers have integrated managerial and technical workers, they have established a variety of forms of segmentation within this upper-level workforce, and have for the most part failed to effect organizational integration of production workers. In contrast, many manufacturers based in Japan and Germany have attempted to reduce managerial segmentation, to integrated shop floor workers into organizational learning processes as well. Consequently, Lazonick and O'Sullivan hold, U.S. companies have been less successful in developing the skill base of their workforce and promoting organizational learning. Among the results of this shortfall are losses of competitiveness in U.S. industry, and the diminution of high quality jobs in the U.S. economy.

To what extent does the diagnostic imaging equipment industry conform with this narrative of industrial change? First of all, we repeat that U.S. diagnostic imaging companies continue to be internationally competitive. Even so, the reduced share of second-tier U.S. manufacturers and the dramatic expansion of Japanese production bear further examination. So it is still of interest to consider the degree of organizational integration in the industry. In a high technology industry such as medical diagnostic imaging, organizational integration can apply to a wide range of actors. Consider five: doctors and hospitals, government agencies and laboratories, suppliers, engineers, and production workers. Pending completion of detailed case studies, the following observations are preliminary.

1) Doctors and hospitals. Doctors and hospitals are important to diagnostic imaging manufacturers in two ways. First, they are sources of academic research. In the 1950s and 1960s, most imaging companies maintained **personal** contacts with academic researchers (Mitchell 1988). Because of the uneven nature of this contact, the businesses learned about advances in academic research primarily through journal articles (Foote 1992)! But from the 1970s onward, manufacturers have invested much more heavily in **institutional** contacts with universities and research hospitals, with foreign producers such as Toshiba (which lacked informal channels for personal contacts) relying particularly strongly on this approach. Second, doctors and hospitals are customers, and manufacturers count on them to offer design advice and to try out prototypes. Deep, long-standing connections between imaging manufacturers and businesses date back to the beginnings of the x-ray industry, and there is no evidence that U.S. producers have invested less in this form of organizational integration than producers in other countries.

2) Government agencies and laboratories. Again, health care in every industrialized country has had a long history of government involvement in research, as funder and in some cases as the site of research. And again, in this form of organizational integration, the United States is on a par with other industrial powers—at least in the health care industry. Japan's diagnostic imaging sector was promoted by MITI, the Ministry of International Trade and Industry. In addition to funding specific research projects, MITI established and supported academic societies devoted to the development of biomedical instrumentation (Mitchell 1988). In the United States, the National Institutes of Health funded research in CT, MRI, and ultrasound (Foote 1992). Other U.S. federal agencies aiding research and development in diagnostic imaging have included the National Science Foundation, the National Institute for Standards and Technology, the Food and Drug Administration, and even the Department of Defense, the Department of Energy, and the National Aeronautics and Space Administration (U.S. Office of Technology Assessment 1978, 1981, 1984).

3) Suppliers. In an industry in which outsourcing is advanced, relations with suppliers are critical. Here U.S. manufacturers appear to diverge from their counterparts, though evidence is mixed. Picker's CT Division, in a World Wide Web posting (Picker International 1997), claims that Picker has "extremely close relationships" with 20 out of 80 suppliers, resulting in "long-term (three years) contracts" and based on "tight communications." It is difficult to assess such claims in the abstract, but practice at Company A paints a mixed picture. While managers at Company A speak of "strategic relations" with a core of suppliers, Company A's vigorous pursuit of lower costs has colored these relationships. Managers from Company A's purchasing organization did tell of efforts to teach suppliers better methods of quality control and inventory management: "We're pretty systematically training our suppliers in statistical process control and other quality programs," stated on manager. But the constant drive to slash costs came through in interviews at Company A as well. On the other hand, the three Japanese companies appear to maintain long-term relationships with suppliers, not infrequently sacrificing short-term cost advantages in order to preserve the benefits of mutual learning.

4) Engineers. Until recently, engineering employment at larger U.S. high technology companies was essentially lifetime employment. But downsizing and outsourcing (especially outsourcing for design and innovation) have increased turbulence in engineering careers. Managers at Company A commented on widespread feelings of job insecurity and dissatisfaction among engineers, undermining company loyalty. They also complained of high turnover, especially among software engineers. One Company A manager spoke of sitting in a meeting with engineers from a European company and estimating that the typical engineer from that company had been with the company 15 to 20 years, compared to five years at Company A. "It may be expensive," he said of the other company's senior engineers, "but they know what they're doing." Japanese companies have maintained the lifetime employment guarantee for engineers, and, like Siemens, tend to retain engineers for long periods.

5) Production workers. Japanese and U.S. companies diverge once more in the degree of organizational integration of production workers. The three Japanese producers use a system of lifetime employment, in-house training, and substantial scope for employee involvement in decision-making. Most U.S. companies offer no long-term employment guarantees. They do voice a rhetoric of continuous learning and employee involvement. Again, Picker's Web posting sets the tone, stating that "On average, each employee receives between one and two weeks of training each year." Picker describes formal and informal problem-solving teams as well as self-managed production teams, and a flattened management structure that "has resulted from the increased empowerment that employees now have" (Picker International 1997).

But first-hand observation of U.S. companies conveys a different impression. At Company A, managers reported that outsourcing and downsizing have created a climate of insecurity, not only among production workers, but among engineers. For most high-level managers interviewed in Company A, the production workforce is essentially invisible, particularly since outsourcing has pushed increasing amounts of production activity beyond the corporation's boundaries. Company A's costs consist overwhelmingly of materials costs, and it is these costs, not labor, that attract most attention. As described in section (2) above, aggregate data for the U.S. diagnostic imaging industry suggest that outsourcing may be a widespread strategy, though we do not have enough evidence to conclude that Company A is representative of U.S.-based producers.

Even at Company B, which **does** attempt to guarantee long-term employment for its core employees, organizational integration of production workers appears to be falling short. Company B has shored up its guarantee by expanding the temporary workforce. But as noted in section (2) above, the size of this temporary workforce has impeded organizational integration of rank-and-file workers.

Thus, while U.S. diagnostic imaging equipment manufacturers avidly pursue organizational integration with doctors, hospitals, and government agencies, they show mixed results at best in organizational integration of suppliers, engineers, and production workers.

Conclusion

Change has been a constant in the U.S. diagnostic imaging equipment industry. Over the last several decades, rapid technological change has fed explosive growth for this industry. But growth may be reaching a plateau in the United States and other mature markets, as the bite of health care cost controls intensifies. The most rapidly growing markets will probably be in Asia, Latin America, and Eastern Europe. This critical juncture in international competition arises at a time when Japanese producers have been steadily gaining market share in the world market. While the market share of General Electric Medical Systems, the world leader, has so far remained secure, the shares of second-tier U.S. companies have shrunk.

As U.S. companies rise to this challenge, they have engaged in over a decade of downsizing and outsourcing, with the aim of increasing efficiency. Based on the limited evidence at our disposal, we cannot fully assess the impact of this restructuring on wages and employment, nor its impact on international competitiveness. But some managers interviewed at U.S. manufacturers expressed concerns that the restructuring weakened loyalty, heightened turnover, and took a toll in the capacity for organizational learning. U.S. firms have invested heavily in organizational integration with physicians, hospitals, and government agencies. But there is some evidence that compared to their Japanese counterparts, they have invested less in integrating suppliers, engineers, and production workers.

The existing case study literature on diagnostic imaging equipment offers little help in sorting out the causal relationships among these patterns. This literature (for example McKay 1983, Friar 1986, Mitchell 1988, 1995, Morone 1993, Steinberg and Cohen 1984, Trajtenberg 1990) focuses squarely on innovation and corporate strategy. But overwhelmingly, for these analysts, the workforce remains invisible.

Additional case study analysis is needed to flesh out the story of the diagnostic imaging equipment industry. Case studies could illuminate a number of questions that have arisen in this report:

• To what extent the U.S. industry's changes in employment and firm size reflect widespread outsourcing, as opposed to other changes.

• The wage effects of outsourcing, through examination of wages at suppliers as well as at the outsourcing companies.

• The specific types of products in which particular countries and companies enjoy competitive advantages.

• In addition to the market regions and product lines in which Japanese imaging equipment companies have been able to expand their market share, the **reasons** for this increase in share.

• The relative degree of vertical integration and outsourcing in U.S. as compared to Japanese diagnostic imaging companies.

• A more careful assessment of the degree of organizational integration, particularly as regards suppliers, engineers, and production workers, in U.S. and Japanese equipment companies.

Through all of these component parts, additional case study research could take the next step in examining the connections among organizational integration, competitive success, and the number and quality of jobs in diagnostic imaging equipment manufacturing firms.

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