Electricity Restructuring, Innovation, and Efficiency[1]

Julie Fox Gorte, The Northeast-Midwest Institute
Tina M. Kaarsberg, The Northeast-Midwest Institute
John A. "Skip" Laitner, U.S. Environmental Protection Agency

ABSTRACT

The United States is now taking significant steps to encourage the restructuring of the electric utility industry. That industry's dominant installed technology, the steam turbine, is no more efficient today than it was in the early 1960s. Much of the motivation behind the restructuring effort is to permit competition from more energy-efficient technologies, particularly gas turbines. For example, the new generation of economically competitive electric supply technologies can lower greenhouse gas emissions by 40-80 percent as a result of their more efficient operation.[2] Technological improvements in the production of electricity are essential to reducing energy costs, air pollution, and carbon dioxide emissions. At the same time, monopoly regulation appears to have stifled productivity and long-term innovation in the U.S. electric utility sector. Other factors also played a part in dampening the incentive to innovate, including overcapacity and the grandfathering of older plants by the Clean Air Act.

Experience in the deregulation of other industries suggests that the capacity for sustained innovation may not be supported by the restructuring process alone. For example, the current electric utility restructuring proposals may produce less than one-third of the savings that are economically available in the generation and use of electricity. Other steps may be needed to encourage innovation within the industry.

Introduction

Utility restructuring intrigues environmental policymakers because utilities burn twice as much fuel as economically needed to generate electricity. As a result, they produce at least twice as much pollution as necessary. The U.S. electric grid system wastes more energy than Japan now consumes for all of its end uses(Laitner, 1998). The current delivered fuel efficiency of the electric grid is about 30 percent — far lower than economically competitive technology now permits. The electric utility industry, under monopoly regulation, has had little incentive to take advantage of technological advances, including electric generating facilities that achieve

---

1. This paper is based on a larger study forthcoming from the Northeast-Midwest Institute. See, Julie Fox Gorte and Tina Kaarsberg, *Innovative Technologies and Productivity*, 1999. The study is supported by a grant from the Environmental Protection Agency's Office of Atmospheric Programs.

2. The lower number compares combined cycle gas turbine technology with the electric grid, and the upper number compares combined cycle gas with an older coal plant, which is assumed to have 20 percent delivered fuel efficiency. Calculations by the authors.

efficiencies approaching 70 percent, or as much as 90 percent when waste heat also is recovered (Kaarsberg et al, 1998).

The production of electricity and thermal energy, using primarily fossil fuels, accounts for the bulk of U.S. carbon dioxide emissions. One-third of the nation's total carbon dioxide emissions comes from burning fossil fuels in electric generators. Another third comes from the production of thermal energy (EIA 1997, EIA 1998). Unlike regulated pollutants that can be scrubbed from power plant smokestacks, the only cost-effective way to reduce net carbon emissions is to burn less fossil fuel. For example, roughly half of the nation's thermal energy could be supplied by the waste heat generated by the electric industry. Although improved efficiency of electricity production is only one route to reduced emissions, it is an important route. Achieving the goals set by the Kyoto Convention will require the development and adoption of innovative technologies across all sectors of the economy.

Most analysts would agree that barriers to innovation must be removed to give to our industries the incentive to maintain an ongoing system of technological advancement. Yet surprisingly little of the restructuring policy discussion — either in the states or in Washington — has focused on how to restructure the giant and critical electric utility industry in ways that spur technological innovation and productivity throughout the American economy.

This paper explores the role of innovation within the electric utility industry. It draws on case studies of restructuring in surface freight (trucking and rail), airlines, and telecommunications. It also explores lessons learned in the restructuring and privatization of the electric utilities in Great Britain. We examine these cases to see what actually happened with the expected results for prices and efficiency. But we also look at whether the restructuring process was equally successful when measured against other yardsticks, including relevant amenities or externalities (e.g., safety, quality of service) and innovation. We contrast these examples with that of the American electric utilities, and draw generalized policy lessons.

The American Capacity for Innovation

Technological innovation is one of America's greatest strengths. It is difficult to name a major innovation made over the past half-century that hasn't been shaped in some significant way by an American inventor, enterprise, or corporation. The national system of innovation in the United States — the traditions, scientific prowess, market systems and signals, and animal spirits — is more conducive to innovation than any other national system in the world.

Our national system of innovation includes a very strong entrepreneurial tradition, which is substantially strengthened by the world's best developed angel and venture capital sectors.[3] It is also anchored by a fierce belief in the power of competition and the market economy. American universities provide technical and scientific education that draws students from all over the globe, especially in science and engineering; they offer nearly half of all doctorates in mathematics, computer science, and engineering (NSB 1996). The United States accounts for almost half of all research and development done in OECD nations. The nation long has been

---

3. Venture capital firms provide money to entrepreneurs--increasingly, to established companies with validated technologies--to achieve significant market penetration. Angels are wealthy individuals who invest at a much earlier stage--often, before a technology is proven--and provide a major source of support for individual investors.

a net exporter or scientific knowledge, engineering know-how, and information. Capital is more widely available in the United States than anywhere else.

Industry-wide Restructuring and Innovation

Many restructured industries — including rail and truck transportation, intercity passenger transportation, airlines, and long-distance telecommunications — have experienced a rapid diffusion of new technologies. In some cases this has resulted in significantly reduced prices. For others, there has been a notable expansion in the range of consumer choices. Some have achieved both. Whether or not deregulation has occasioned a greater capacity for sustained innovation, or changed the character of innovation, has yet to be established.

Why Regulated Monopolies?

Certain sectors were considered natural monopolies because the economic scale of production is so large that having more than a single supplier would raise costs. Average costs of production fell as size increased over the entire relevant range of production, all the way up to complete market dominance and saturation. Besides strong scale economies, other characteristics of natural monopolies included large initial costs for capital investment, limited ability to store the product, and limited ability to transport the product, generally requiring a transmission network. Yet, recognizing the ability and tendency of monopolies to manipulate prices in order to extract excessive profits from their customers,[4] government agencies created a category of regulated monopolies in several industry sectors. In theory this regulatory approach allowed customers to benefit from the lower-cost technologies available only to the monopolist but to not pay monopoly prices.

Despite the theory, regulated monopolies turned out to be inefficient. The lack of competition inherent in monopoly, according to one analyst, "...causes an industry to accumulate substantial managerial slack or 'X-inefficiency;' that is, firms do not minimize the cost of producing a given level of output (Winston 1998)." Moreover, regulated firms are somewhat cushioned from external shocks. They tend to react less effectively than firms facing competition. When oil prices rose during the energy shocks of the 1970s, for instance, electric utilities had the option of asking regulators to raise prices. In the rest of the economy, this was not the case, and consumers of electricity responded by switching to less costly fuels and adopting a wide range of energy efficiency measures. These reactions had a profound effect on energy efficiency, which persisted long after oil prices had fallen.

Examples of Regulated Monopolies That Were Deregulated

Some industries were never really a good fit as natural monopolies. Airlines and freight companies are good examples. They were simply deemed too important to be left to the

---

4. In economics, the term used to describe excess profits is "monopoly rent." It refers to the fact that monopolists can charge whatever the market will bear, and thus reap what economists regard as excess profits, greater than what would be needed to keep the firm in business.

vicissitudes of competition, which might mean that some customers receive no or inadequate service, or that companies delivering important services could force society to make unpleasant choices in order to keep receiving the service.

In other sectors, such as telecommunications and electric utilities, the transmission systems represent an enormous capital investment that would be expensive and redundant to duplicate in order to allow competition. But other parts of the systems—customer premises equipment (e.g., phones, handsets, PBXs) in telecommunications, and electric generators in utilities—are not characteristically natural monopolies. Similarly, most electric restructuring schemes leave transmission and distribution substantially untouched, and introduce competition and deregulation to the business of electricity generation. If we manage to bring competition to that section of the electric power industry, what benefits could we expect? There are several examples that can serve as analogues.

The United States has deregulated[5] or restructured (deregulated to some degree) several industries, including airlines and motor carriers (freight), railroads, banking, natural gas, long-distance telecommunications, and cable television. In all cases where significant deregulation was undertaken, there have been significant improvements in efficiency. The impact on externalities — e.g., the quality of services, the availability of universal service, and environmental effects — are less predictable. The effect on technology development and adoption are predictably positive in the immediate term, but much harder to predict after the first wave of adaptation passes.

Deregulation's Impact on Productivity

In general, deregulation does reduce costs and prices and increase many measures of productivity. That is what has happened since the late 1970s in trucking, rail, air travel, long-distance telecommunications, natural gas, cable TV and British electricity. Examples of consumer savings in several such industries are shown in Table 1. In nearly every case, prices and costs have come down, and financial performance has gone up.

Table 1. Deregulation Impact on Consumer Prices.

Industry	**Magnitude of Productivity Effect (estimates)[6]**
Airlines	15 - 22 percent drop in fares overall
Rail and Trucking	$20 billion in annual benefits to shippers (lower rates); rail profits increased $2.9 billion annually [1988 dollars]
British Electric Utilities	2 percent drop in prices between 1991 and 1995; profits increased 6 percentage points (30 percent) in one year (1994 to 1995)

5. Full deregulation includes freedom from regulated prices as well administered constraints on the entry to and exit from different segments of the market.

6. More background on these and other productivity impacts are provided in the full study cited in footnote 1.

In addition, there have been revolutionary changes in the technology used by these industries.[7] Thus, we expect that electric utility restructuring also will be accompanied by substantially increasing productivity, lower prices, and deployment of efficient new technologies. For example, widespread adoption of new electric generating technologies is almost certain to improve the efficiency of production, measured by electrical output per unit of fuel input. Since fuel is the largest single cost component in electricity production, this alone ought to reduce production costs, and, possibly, prices.

Deregulation's Impact on Innovation

Despite obvious pricing benefits, however, overall innovation may have suffered in some key industries. Consider air transport, in which declining costs over the past several decades were the result of hardware innovation. The introduction of the jet engine in the 1950s and 1960s, the increase in aircraft sizes and loads made possible by the turbofan engine and wide-body aircraft, the improved fuel efficiency of aircraft engines, and the improved airframe designs to permit laminar flow all helped to reduce an aircraft's operating costs. One analyst (Hanlon 1996) argues that in the leaner environment of deregulation the airlines cannot afford to continue their support of aeronautical innovation Others warn that reductions in military aeronautics development will cut still deeper into the pace of change in aircraft technology (Morrison and Winston 1995).

While the military cutbacks have nothing to do with deregulation, the combined effect of airlines' withdrawal of support for aeronautics technology, and the shrinking military programs, is almost certainly a slowdown in the pace of technology advance. The most eagerly awaited big-bang innovations in aeronautics — economical supersonic transport at Mach 1.2, or Mach 2-5 passenger transport, or even hypersonic air travel — are probably decades away from commercial reality, under today's market conditions.

Deregulation is different for each industry, but there are some common elements. There is strong evidence that introducing competition will greatly increase the incentive to improve short-term financial performance, which will lead to cost-cutting measures. Some of the cost-cutting is likely to be passed on to consumers, though not all of it; profitability often improves, but not always. If an industry is truly opened to competitive forces — which was not the case in British electricity privatization efforts — we can probably expect a wave of new market entrants. This, in turn, will be followed most likely by a period of consolidation, however.

The relationship between deregulation and technology is not simple. One fairly reliable result of even partial deregulation is an explosion in availability of new technologies, in both hardware and business management. The initial flood of new technology is often a pent-up wave. It does not necessarily portend a continuing surge of accelerated technological progress. In fact, deregulation can be hard on technology development, especially in the long run. Airlines' support for aeronautical technology development, as noted above, declined as pressures for cost containment grew. British utilities, even with relatively little real new competition, slashed research and development funding. The story in telecommunications is somewhat

---

7. In this case and elsewhere in this paper, we use the word "technology" to encompass innovations in both systems and services as well as hardware and equipment.

different, and less conclusive. Research and development expenditures have fallen, at least in the primary telecommunications sector, but telecommunications patenting has expanded strongly. Basic research, once the metier of Bell Labs, has been cut back drastically, to the point where some analysts of science and technology policy fear for our ability to sustain a healthy rate of innovation.

Innovation in the Electric Utility Industry

Changing technology is widely regarded as one of the principal factors behind utility restructuring (or deregulation) in the United States.[8] One summary of restructuring issues notes that "[a]dvances in power generation technology, perceived inefficiencies in the industry, large variations in regional electricity prices, and the trend to competitive markets in other regulated industries have all contributed to the transition (EIA 1998)." As of April 1999, 16 states have enacted restructuring legislation, four have issued a comprehensive regulatory order, four have legislation or regulatory orders pending, and 24 are investigating the issue, as is the District of Columbia. So far, however, few states have really addressed how to assure that new, more efficient technologies can compete fairly with the established set of technologies and companies.

Of course, the fundamental reason for deregulation (at least in the United States) is to reduce costs, resulting in lower electricity prices. Improved thermodynamic efficiency is only one way to get there; improved business efficiency is another (Brower 1996).[9] Still, technological innovation in the production of electricity is one of the most effective means to keep costs low and productivity high in the long run.

Environmental Concerns

But will this technological wave breaking over the electric utility industry be beneficial when measured by environmental impact? Here, the answer differs widely in both magnitude and direction depending on policies and rules that have yet to be implemented (or, in some cases, written). New electric generating technologies have far higher electrical output per unit of fuel input and thus lower emissions per unit of electricity generated. Whether this benefit leads to lower emissions in general, or in the areas with the worst air pollution problems, depends greatly upon: (1) how rapidly new technologies are adopted; (2) how much electricity prices change over time; and (3) how companies position themselves over the long term within the restructured market.

---

8. Deregulation is the withdrawal of the state's legal powers to direct pricing, entry and exit of nongovernmental bodies, according to Clifford Winston, "Economic Deregulation: Days of Reckoning for Microeconomists," *Journal of Economic Literature* 31, 1263-1289. Thus "Restructuring" is used more often than "deregulation" in referring to the electric power sector. because full deregulation of all subsectors of the industry — transmission, distribution, and generation — is not contemplated.

9. For example, when the British utilities were privatized and restructured, they made deep cuts in their labor forces; some American utilities are outsourcing parts of their operations so as to streamline the companies' core businesses. See, for example, (Brower 1996) and PRNewswire, "CSC Enters Business Process Outsourcing Agreement with Enron Energy Services", El Segundo, Calif., April 16, 1997, posted on ENERGY CENTRAL (http://www.energycentral.com).

Unfortunately, today's least expensive generators are often older coal-fired plants that were "grandfathered" by the Clean Air Act of 1970 that required all "new" power plants to meet new source control regulations. It also required all existing power plants to undergo "new source review" if they were substantially upgraded--which also had an unfortunate impact on innovation. Seventy-seven percent of U.S. fossil-fuel-powered plants are grandfathered; the average fossil fuel plant began operating in 1964; one-fifth of U.S. power plants are more than 50 years old. Replacements and capacity additions have come very slowly. Planned new capacity in the decade between 1998 and 2007—about 40 gigawatts—amounts to only about 6 percent (or 0.6 percent per year) of existing capacity (EIA 1998b).

How Much will Utilities Innovate?

As critical as innovation is to the performance of the industry, there is no good statistical data series for the electric utilities that measures that sector's pace of innovations. However, strong evidence exists that: (1) there is little incentive for innovation in the absence of competition; and (2) large firms with stable market shares rarely initiate radical technological development, or provide incentives for their employees to undertake major development (Utterback and Suarez 1993).

With restructuring, new entrants and changed business plans might bring much new technology on line more quickly than the 1998 power plant inventory indicates. On the other hand, there is little in the utilities' performance over the past few decades to inspire confidence in their ability to initiate and sustain technological progress toward greater efficiency and reduced emissions. Instituting true competition should make efficiency of generation and distribution much more important to the industry, but it probably is not enough to guarantee sustained progress. Deregulation or restructuring often facilitates the adoption of efficient technologies, but it does little to change the basic pattern of innovation underlying the industry in question.

Electric utilities "innovation" pattern (in generation) appears to be to lock-in to a new technology every 40 or 50 years. They are widely regarded as technologically moribund — for example, they spend far below the industry average on research and development (NSF 1997). Telecommunications' pattern, on the other hand, has been to be one of the nation's most innovative sectors. All things equal, we would expect telecommunications companies to continue inventing and introducing new products, long after their adjustment to deregulation. In contrast, the electric utilities would be expected to undergo a flurry of investment in new plant, equipment, and service provision, and then settle down into a new pattern of locked-in technology.

Restructuring the electric utility sector is likely to be accompanied by a wave of new technology. In fact, the existence of more efficient and economical new technologies — notably natural gas combined-cycle combustion turbines — is part of the impetus for restructuring. The rules of restructuring will have a great deal to do with how costs are brought down, and how that, in turn, affects the deployment of more efficient generating technologies over the next decade and beyond. If the rules change little, utilities could simply lock in a new generation of technology, only to find that in thirty or forty years that it will be just as difficult to displace as the coal-fired steam turbines are today.

Utilities' Innovativeness as Measured by R&D Intensity

The most common and perhaps simple measure of innovation, as poor of a proxy as it may be, is the intensity of research and development (R&D) expenditure per dollar of net sales. (It should be noted that R&D is a much better proxy for the ability to deploy new innovations in the future — 5 to 50 years from now — than for the likelihood that new technologies available today will be diffused.) Using this measure, electric utilities and gas companies are not especially innovative. Among electric and gas companies performing research and development, R&D intensity was only 0.2 percent, and declining. This compares with an all-industry average of 3.4 percent, and 3.6 percent in R&D-performing manufacturing industries (NSF 1997). Such a comparison is not completely fair since the electric and gas utilities are in a category that also includes sanitary services, which may be even less R&D-intensive than electric and gas utilities. Moreover, much of the R&D that contributes to the efficiency of electricity production is done in manufacturing industries—for instance, work on combined-cycle gas turbines and microturbines has been done in the machinery industry, which has an R&D intensity of more than 5 percent.

Utilities' Innovativeness as Measured by Thermal Efficiency

The stagnation of efficiency in electricity production, confirms the utilities' slow pace of technological change. For the first half of the twentieth century, electric generation technology improved in a series of jumps, rising from less than 10 percent at the turn of the century for small 5 megawatt (MW) units to about 37 percent in the mid-1950s for 300 MW units. Since then, however, there has been very little improvement, even though the size of the state-of-the-art steam unit increased to more than 1,000 MW.

In the 1970s, technologies began to emerge that were more efficient than, and economically competitive with, the traditional large-steam-turbine technology of central electricity production. But that era's energy shocks, and the resulting demand-side energy efficiency measures that the nation undertook, led to a large bubble of overcapacity in electric generation in the early 1980s, reducing the demand for new power plants. Finally, the Clean Air Act's grandfather clause allowed a generation of relatively dirty coal-fired power plants to continue operating while new plants were subject to more stringent source performance regulations. The result of all these factors was very little investment in new technologies or new plants in the 1980s and 1990s.

Utilities' Innovativeness as Measured by Productivity Growth

Productivity growth within an industry is another proxy for innovation. Although it is seen by some as a weak indicator of innovation, there is often a strong relationship between productivity and innovation. Until 1974, the growth in productivity for both the gas and electric utilities compared fairly well to all private businesses. Following the oil price shocks in 1974 and through the 1980s, productivity slowed down throughout the U.S. economy. But productivity plateaued more emphatically with utilities than with most other private businesses, and certainly to a greater extent than with manufacturers.

Utilities' Innovativeness as Measured by Capital and Production Investments

Economic researchers (Israilevich and Kowalewski 1987) tested the hypothesis that rate-of-return regulation retarded the pace of technical change in electric utilities over the 1965-1983 period. They found that regulation indeed had curtailed implementation of efficient capital and production systems among Ohio's electric utilities. They also found that the negative impact on technical change was greatest when regulation was most constraining, such as during the energy shocks of the 1970s. Though this study has limited geographic scope and is somewhat dated, it is consistent with both other evidence and the judgment of informed observers as to the utilities' incentives and propensity to expand the technological envelope.

Future Opportunities

Based on the record of other industries and the restructuring of the British electric industry, the long-term outlook for restructuring-induced innovation within the electric utility industry is highly uncertain. This conclusion is made despite the potential contributions from many new technologies in all areas of the industry. The short-term outlook, however, is much more hopeful (Munson and Kaarsberg 1998).

Most analysts expect over the next few years a wave of new technology in electricity production, led by combined-cycle combustion turbines. New central electric generating capacity is quite likely to be all, or almost all, combined-cycle gas units. Eventually this capacity will replace (or displace) some of the coal- and oil-fired plants whose aging equipment produces significantly higher levels of emissions. The advent of new, highly efficient gas-fired technology will undoubtedly improve the emissions picture for electricity production — at least on a per unit of output basis. Depending on the growth of demand for electricity, and the implementation of efficient technologies through the electricity-consuming sectors, the more efficient technologies may even contribute to an absolute reduction in total emissions. The Energy Information Administration's latest published forecast is for 4.5 percent per annum growth in natural gas electric generation, far higher than the 0.9 percent per annum growth in total electric generation. For comparison, growth in coal-fired generation is forecast at 1.0 percent per year (EIA 1999).

There are, as well, many other new technologies that could reshape the electric power industry, according to some analysts (Morgan and Tierney 1998). These include solid-state power electronics to control the flow of power to individual lines and end-use devices; advanced sensor, communication, and computation technologies that allow greater flexibility in control and metering; high-temperature superconductivity that enables "lossless" transmission, higher-efficiency generators and motors, and short-term storage capacity to avoid surges; fuel cells that convert hydrogen to electricity with no CO_2 emissions; efficient long-term storage technologies; low-cost renewable electricity; and gasification technologies.[10]

Some of these technologies allow for much more efficient and accurate use of the grid. Some offer greatly improved ability to reduce the emissions of air pollutants and greenhouse gases associated with electricity production, while others promise greater system-wide

---

10. Morgan and Tierney do not include gasification in their list of especially promising technologies, but suggest instead fossil fuel decarbonization.

efficiency. Combined, they offer the opportunity to change the electricity industry's structure, from a system of giant generating plants linked to customers by a vast transmission and distribution network to a system that permits distributed generation, or small-scale power generation, based on small turbines, fuel cells, or renewable technologies. Distributed generation also should greatly increase the use of cost-effective combined heat and power (CHP) systems that capture and use the heat that is otherwise wasted in the production of electricity by conventional generation plants. CHP offers the ability to improve dramatically the fuel efficiency of electricity generation (Kaarsberg and Elliott 1998).

Conclusions

Some analysts clearly see a bright technological future for the industry. One investment analyst (Holman 1999), for example, says, "Technologies that bring even marginal improvement to the efficiency of the industry should create sizable market opportunities." Holman's analysis points out, for example, that deregulation gives companies much more opportunity to exercise discriminatory pricing, charging more to peak-load customers (or, in the case of the airlines, more to business travelers). Distributed generation, according to Holman, is a good way for consumers to buy freedom from peak power rates, as is electricity storage. Restructuring, therefore, ought to provide a boost to distributed generation and storage technologies.

However, the fact that a lot of efficient technology is just over the horizon does not mean that it will be adopted. Nor does it imply that a restructured industry will regard continued technology development as a major priority. For example, the recent Administration analysis of its proposed restructuring legislation indicates that, if enacted, carbon emissions might be reduced by as much as 40 to 60 million metric tons by 2010 (DOE 1999). However, this reduction is less than one-third of what might be economically available through a combined set of policies that encourage cost-effective high efficiency/low carbon technology deployment (Koomey et al 1997, DOE 1997).[11] The outcome depends a great deal on how the restructuring process, together with other complementary policies, is actually carried out. It also will depend heavily on how utilities are allowed to recover stranded costs. Systems that impose heavy transition charges (e.g., exit fees), or backup power rates on new entrants, will tilt the playing field in favor of existing utilities, which are huge, multi-billion-dollar corporations with enormous stakes in electric restructuring. As one might expect, those power companies are exerting enormous effort to make sure that restructuring gives them a competitive edge.

The greater the leverage of the established companies within a restructured electricity market, the dimmer the prospects for continued innovation in that industry. Electric utilities already have cut back substantially on research and development, and are likely to reduce still more as deregulation puts downward pressure on costs and prices. Since electric utilities have no tradition of technological dynamism, as did the aircraft and telecommunications industries, they are less likely to adopt a continued commitment to innovation through the restructuring

---

[11]. See, Koomey. et al 1998 Although an assessment of the economic impacts of a cost-effective reduction in carbon emissions throughout the entire economy, the analysis estimated that a minimum of 170 million metric tons of carbon reductions could be obtained through improvements in the generation and use of electricity by 2010. Other studies (e.g. DOE 1997, Energy Innovations 1997) have pointed to even larger, but still cost-effective, reductions that might be available as a result of appropriate policy initiatives.

process.

It is conceivable that electric utilities could become much more innovative after restructuring, due to the pressures of competition. Yet without a critical mass of new competitors, each bringing new technologies to the market, the likelihood of the industry changing its priorities is understandably small. The large established companies that dominate their markets rarely have been the source of radical innovation. Major technological advances simply do not come from dominant firms with long-established technologies, and tests of this conclusion in the automobile, television, typewriter, TV tube, transistor, integrated circuit, electronic calculator, and supercomputer industries bear this out (Klein 1977, Utterback and Suárez 1993).

Our conclusion, then, is that introducing competition to a regulated monopoly such as the U.S. electric industry will greatly increase its productivity in the near term. This policy should result in the immediate application of cleaner and more efficient technologies (e.g., gas combined cycle generating units). Such competition is also a necessary, but not sufficient condition for innovation. To sustain innovation, environmental and technology policymakers must combine the restructuring process with other technology and environmental policy tools to keep the electric services market open to new and innovative competitors.

Acknowledgements

Drs Gorte and Kaarsberg would like to acknowledge financial support for this research from the U.S. EPA Office of Atmospheric Programs. All of us thank our reviewers including Tom Casten, David Klein, John Maulbetsch, Lewis Milford, Joel Palley and Dan Steinmeyer.

References

Brower, Michael C. 1996. *The British Electric Utility Restructuring Experience: History and Lessons for the United States*, National Council on Competition and the Electric Industry, October 1996.

[DOE] U.S. Department of Energy. 1997a. Interlaboratory Working Group (ANL, LBNL, NREL, ORNL, and PNNL) on Energy-Efficient and Low-Carbon Technologies. *Scenarios of U. S. Carbon Reductions Potential: Impacts of Energy Technologies by 2010 and Beyond.* Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. http://www.ornl.gov/ORNL/Energy_Eff/CON444.

[DOE] U.S. Department of Energy, "Comprehensive Electricity Restructuring Plan: Benefits of the Proposal," (Washington, D.C.: April 1999). http://home.doe.gov/policy/ceca.htm.

[EIA] Energy Information Administration, *Annual Energy Outlook 1999*, (Washington, D.C.: U.S. GPO, 1999), data tables in Appendix A.

[EIA] Energy Information Administration, 1998. *The Changing Structure of the Electric Power Industry: Selected Issues, 1998*, DOE-EIA-0562, (Washington, DC: July 1998), p. ix.

[EIA] Energy Information Administration, 1998a. *Inventory of Power Plants in the United States*, December, posted on http://www.eia.doe.gov/cneaf/electricity/ipp/ipp_sum.html, and supporting data tables.

[EIA] Energy Information Administration. 1997. *Emissions of Greenhouse Gases in the United States 1996*. DOE/EIA-0573(96). Washington, D.C.: U.S. Department of Energy.

Hanlon, Pat. 1996. *Global Airlines: Competition in a Transnational Industry*, (Oxford: Butterworth-Heinemann Ltd., 1996).

Holman, Hugh F. 1999. *Rejoice Re: Juice Redux. An Update on Our Continuing Quest to Find Profit in the Restructuring of the Electric Utility Industry*, BancBoston Robertson Stephens, Boston Mass, April 12, 1999. http://www.rsco.com.

Israilevich, Philip and K.J. Kowalewski, 1987. "The Effect of Regulation on Ohio Electric Utilities," *Federal Reserve Bank of Cleveland Economic Review*, First Quarter, 1987 pp. 10-19.

Kaarsberg, T.M. and R. Neal Elliott. 1998. "Combined Heat and Power: Saving Energy and the Environment," *The Northeast-Midwest Economic Review*. March/April. Washington, D.C.: Northeast-Midwest Institute. http://www.nemw.org/ERheatpower.htm.

Kaarsberg, T.M., R. Neal Elliott and Mark Spurr. 1999. "An Integrated Assessment of the Energy Savings and Emissions-Reduction Potential of Combined Heat and Power," these proceedings, ACEEE Industrial Summer Study June 1999.

Klein, Burton, 1977. *Dynamic Economics* (Cambridge, MA: Harvard University Press, 1977).

Koomey, Jonathan G., R. Cooper Richey, Skip Laitner, Robert J. Markel, and Chris Marnay, Technology and Greenhouse Gas Emissions: an Integrated Scenario Analysis Using the LBNL-NEMS Model, EPA 430-R-98- 021, U.S. Environmental Protection Agency, Washington, DC, September 1998. http://enduse.lbl.gov/Projects/GHGcosts.html.

Laitner, Skip. 1998. "Comparison of Waste Heat Generation in U.S. Electricity Generation with Total Energy Consumption in Selected Countries and World Regions," (Working Memo). Washington, D.C.: U.S. EPA, Office of Atmospheric Programs.

Morgan, M. Granger and Susan F. Tierney, "Research Support for the Power Industry," *Issues in Science and Technology*, Fall 1998, pp. 81-87. http://www.nap.edu/issues/

Morrison, Steven A. and Clifford Winston, *The Evolution of the Airline Industry*, (Washington, DC: The Brookings Institution, 1995), p. 153.

Munson, R, and T. Kaarsberg. 1998. "Unleashing Innovation in Electricity Generation," *Issues in Science and Technology*. Spring. Washington, D.C.: National Academy of Sciences. http://www.nap.edu/issues/14.3/munson.htm

[NSB] National Science Board, *Science and Engineering Indicators*—1996 (Washington, DC: U.S. Government Printing Office, 1996), NSB-96-21, p. 2-3.

[NSF] National Science Foundation, Research and Development in Industry: 1997 (Preliminary Tables), 'Table A-21. Total (company, Federal, and other) industrial R&D funds as a percent of net sales in R&D- performing companies, by industry and size of company: 1987-97, http://www.nsf.gov/sbe/srs/srs99411/start.htm.

Utterback, James M. and Fernando F. Suárez, 1993. "Innovation, competition, and industry structure," *Research Policy* 22(1), p. 2-3.

Winston, C. 1998. "U.S. Industry Adjustment to Economic Deregulation," *Journal of Economic Perspectives* 12(3), Summer 1998.