Productivity growth slows in the organic chemicals industry

Productivity growth was highest from 1963 to 1974; however, overall declines in hours and employment have characterized the 1974–85 period

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Output per employee hour in the manufacture of certain industrial organic chemicals—such as ethylene, acetic acid, and formaldehyde—rose at an average annual rate of 4.1 percent between 1963 and 1985, compared with 2.3 percent for all manufacturing.[1] (The industry accounts for nearly four-fifths of total employment in organic chemicals manufacturing.) Over the period, output increased at a faster rate, 5.0 percent a year, than employee hours, which rose by only 0.9 percent.

Productivity growth was greatest from 1963 to 1974, when it increased at a rate of 6.6 percent a year. From 1974 to 1979, the rate dropped to 3.2 percent, reflecting a slowdown in output growth and an increase in the employee hour rate. During the years 1979 to 1985, the productivity rate slowed further, to 1 percent, as both output and hours declined. (See table 1.)

Year-to-year movements in output per hour were volatile, ranging from a 21-percent increase in 1983 to a 17-percent decline in 1975. From 1963 through 1979, the magnitude of change in productivity was generally about the same as, or slightly less than, the corresponding change in output. After 1979, productivity and output still moved in the same direction, but the annual productivity changes were sometimes greater than output changes, largely attributable to a sustained decline in employee hours.

A period of rapid gains. Labor productivity growth over the 1963–74 span was driven by large increases in output (8.4 percent a year), which were spurred, in part, by product innovations.[2] Employee hour growth for the same period was moderate—1.7 percent a year. A major portion of this capital intensive industry's output is made in plants with automated, continuous processes. Construction of more efficient, high-volume plants during this period made for greater economies of scale. In ethylene production, for instance, a major effort to increase plant capacity started in the mid-1950's and continued until a plateau was reached in the late 1960's. Advanced computer technology, especially in the area of process controls, was also a major factor behind the productivity gain.[3] (Computerized controls are essential in high-volume, continuous processing characteristic of the industry.)

Because the number of production workers in large organic chemicals plants is fairly constant over a wide range of output levels, labor productivity changes in the short run largely reflect changes in capacity utilization and the age composition of capital stock.[4] During the early part of the 1963–74 period, effective operating capacity for organic chemicals was high. Some excess capacity did develop after 1966, following rapid modern-

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Table 1. Indexes of productivity, output, and employment in the industrial organic chemicals industry,[1] 1963-85

Year	Output per hour	Output	Employee hours	Employees
1963	46.7	35.5	76.0	76.1
1964	50.1	39.2	78.3	77.6
1965	55.3	45.3	81.9	81.6
1966	58.0	49.2	84.9	85.2
1967	56.3	47.5	84.3	84.7
1968	58.1	51.6	88.8	87.8
1969	61.9	56.9	91.9	90.5
1970	65.5	60.7	92.7	92.8
1971	72.6	64.2	88.4	89.2
1972	81.5	73.3	89.9	91.2
1973	90.4	83.1	91.9	91.5
1974	102.8	94.6	92.0	91.3
1975	85.3	78.6	92.1	93.4
1976	93.4	90.3	96.7	97.3
1977	100.0	100.0	100.0	100.0
1978	102.8	104.3	101.5	101.4
1979	113.4	116.7	102.9	102.6
1980	98.9	102.4	103.5	104.4
1981	103.9	103.9	100.0	99.7
1982	87.2	85.3	97.8	99.6
1983	105.3	98.8	93.8	95.0
1984	114.0	104.2	91.4	92.1
1985	112.4	95.9	85.3	85.9
	Average annual rates of change (in percent)			
1963-1985	4.1	5.0	0.9	0.9
1963-74	6.6	8.4	1.7	1.7
1974-79	3.2	5.9	2.6	2.5
1979-85	1.0	-2.1	-3.1	-2.9

[1] Not elsewhere classified.

ization efforts (including debottlenecking) and new plant construction, but the mix of capital stock had become more efficient. During extended periods of excess capacity, it is common practice to mothball the older, smaller, less efficient plants. Thus, the negative effects of overcapacity on industry productivity are somewhat offset by having more efficient plants in operation.[5]

The slowdown. Plant replacement continued during the 1974-79 period. Further improvements in computer hardware and software also were made. However, the positive influence of these changes was offset by declining capacity utilization and a slowdown in process innovation.[6] Moreover, although the rate of output growth slowed, the growth rate of employee hours increased faster than during the previous 11 years.

By this time, economies of scale had largely been realized in many commodity chemicals plants.[7] Thus, the productivity benefits in building a new plant were less than in the earlier period. Also, as demand slowed, the utilization of many of the very large plants declined, lessening their efficiency and lowering productivity.[8] In 1975, for instance, when output dropped by 17 percent, the industry operated at only 74 percent of capacity—and productivity fell 17 percent. The situation was aggravated by the continued construction of large plants even as demand fell off. The lengthy period involved in plant planning and construction, combined with the belief that high sales growth would soon resume, contributed to the overbuilding.[9]

A volatile period. The 1979-85 period, during which productivity increased moderately, was marked by an overall decline in output accompanied by reductions in employment. Annual changes in productivity were very erratic—due largely to big swings in output.

There was some apparent progress in technical innovation, particularly in improved automation in the production of specialty chemicals.[10] (Specialty chemicals are usually batch-produced in low volume.) However, inasmuch as the commodity chemicals sector dominates the industry and its productivity changes are largely determined by capacity utilization rates, overall industry productivity improvements were dampened by several years of excess capacity.[11] For example, in 1980, when productivity dropped 13 percent, capacity utilization for plants producing ethylene, a major feedstock in the manufacture of other products and the most important industry product in terms of volume, was 71 percent. Operating rates recovered briefly in 1981, but fell again by the end of the year to 70-75 percent. (Productivity increased only 5 percent.) By 1982, when the utilization rate was 60 - 65 percent and many plants were closed, productivity again dropped sharply. Ethylene, formaldehyde, and propylene plants were running at less than 60 percent of capacity.

The upward climb in productivity in 1983 and 1984 mostly reflected increases in output. Producers of ethylene and other commodity chemicals kept their older, less-efficient plants mothballed because of the excess capacity in the more-modern plants currently operating. Thus, the surge in demand was met without having to initiate plant startups, which are costly in both dollars and labor time.[12] There was no significant change in productivity in 1985.

Products

Organic chemicals can be divided into two groups—commodity and specialty. Commodity chemicals are produced and sold in large quantities and usually are used as feedstocks in the synthesis of other organic chemicals. Some commodity chemicals also are sold to manufacturers outside the industry, such as those in plastics production. Specialty chemicals are made in much smaller quantities—a whole year's supply sometimes will be produced in a few days. Some of these chemicals are made to individual customers' specifications; others are simply low-volume stock chemicals.

Few organic chemicals are direct consumer products. They are purchased by companies in many different industries and have a vast array of end uses. (See exhibit 1.) Synthetic acetic acid, for instance, is used by chemical companies as an intermediate to produce other organic chemicals such as vinyl acetate, and by industries outside chemicals manufacturing, like textile processing. In addition, some acetic acid production processes use other organic chemicals as a feedstock (such as methanol and acetaldehyde), while ethylene is used only as a feedstock in further chemical processing. Other industries that use organic chemicals include pharmaceuticals, automobiles, synthetic tires, cosmetics, building materials, household appliances, and flavorings. The following tabulation shows the volume rank of the industry's top 13 chemicals:[13]

1. Ethylene
2. Propylene
3. Ethylene dichloride
4. Vinyl chloride
5. Terephthalic acid (acid and ether)
6. Methanol
7. Ethylene oxide
8. Formaldehyde, 37 percent
9. Ethylene gylcol
10. Acetic acid
11. Propylene oxide
12. Acrylonitrile
13. Vinyl acetate

Output trends

Over the long term, output increased at a rate of 5 percent, compared with the 2.5-percent rate for all manufacturing. This, however, reflected a high growth rate (8.4 percent) for the first 11 years, followed by a rate of only 0.8 percent over the remaining 10 years.

High growth period. From 1963 to 1974, output grew at an average annual rate of 8.4 percent, with 6 years of double-digit increases. During this period, total manufacturing output rose at a rate of 3.3 percent. Low cost, readily available petroleum-based feedstocks and rapidly developing markets helped fuel the output growth.[14]

The increased demand came mainly from the expanding plastics and synthetics industries. Synthetic fibers output, for example, increased at an average annual rate of 11.7 percent from 1970 to 1974, while the organic chemicals industry's output was rising 12.1 percent. (See table 2.)

Energy shortages—the next 5 years. The period of high output growth ended in 1975 when output dropped sharply (16.9 percent). The 1975 output drop was largely attributable to the general decline in industrial activity, but materials shortages, specifically of petroleum-based products, may also have been limiting factors. The oil embargo of late 1973 and early 1974 and the imposition of an oil import fee in early 1975 restricted the production of petroleum-related feedstocks essential to the industry.[15]

In 1976, output increased 14.9 percent as demand rose and the supplies of petroleum-related products improved, although they generally were priced much higher. Natural gas supplies continued to be somewhat limited. Output grew at an average annual rate of 8.5 percent for the next 3 years, which was slightly above the industry's 1963–74 rate.

Even though the industry's overall rate of output increase slowed over the 1974–79 period, it ran higher than that for all manufacturing—5.9 percent versus 4.5 percent. Major end-use industries showed mixed output trends.

Exhibit 1. Selected organic chemicals and their end uses

Chemical	End use
1,3 Butadiene, made in chemical plants	Synthetic rubber, fibers
Ethylene or ethene	Plastics, antifreeze, synthetic fibers, solvents, anesthetic, welding materials, gasoline additives
Propylene or propene	Plastics, synthetic fibers
Chloroform or trichloromethane	Freon 22, refrigerant, propellants, resins, pencillin solvent
DDT or dichlorodiphenyltrichloroethane	Insecticide, scabicide
Dichlorodifluoromethane	Freon 12, refrigerant, aerosol propellant
Ethyl chloride	Local anesthetic, solvents, refrigerant, gasoline antiknock
Ethanol or ethyl alcohol	Solvents, cosmetics, toiletries
Ethylene glycol or 1,2-Ethanediol	Antifreeze, polyester, Mylar films
Methanol or methyl alcohol	Plastics, fibers, adhesives, solvents, rubbing alcohol, antifreeze, octane booster
Ether or diethyl ether	Solvents, anesthetic
Ethylene oxide	Polyester fibers, films, antifreeze, surfacants, sterilizers, pharmaceuticals, synthetic rubber, paint, adhesives, resin, cosmetics, brake fluid, solvents, pesticides
Mustard gas or dichlorodiethyl sulfide	Chemical warfare agent
Formaldehyde or methanal	Plastics, adhesives, preservatives, dyes, disinfectants, fertilizers
Acetone or 2-propanone	Rayon, plastics, solvents, paints, electronic cleaners
Acetic acid or ethanoic acid	Solvents, rubber manufacturing, photochemicals, plastics, pharmaceuticals, fibers
Ethyl acetate	Rayon, pharmaceuticals, coatings, solvents, perfume, flavorings, paint, plastics
Methyl salicylate (wintergreen)	Perfume, flavorings, counterirritants
Hexamethylenetetramine or methenamine	Vulcanizing accelerator, urinary tract antiseptic, gas mask absorbant, resins, explosives
Acrylonitrile or propenenitrile	Fibers, plastics, synthetic rubber, mustard gas

Slowdown in the 1980's. In 1980, there was another large output decline (12.3 percent) as petroleum-based feedstock supplies were once again strained and the level of industrial activity slowed. There was a small increase in 1981, but for the industry and the general business economy, the rebound was short-lived. The following year, the organic chemicals industry suffered its largest single-year drop, 17.9 percent, largely attributable to a falloff in final demand. Output rebounded strongly in 1983, increasing almost 16 percent, as feedstock supplies were generally good and prices favorable. The growth in demand for automobiles and housing, which helped stimulate the 1983 increase, carried through to 1984, though output grew at a much slower rate. The following year, output once again declined, as industrial production slowed. The one exceptional increase in 1983 could not offset output declines in other years, resulting in an annualized 6-year rate of change of −2.1 percent. (All manufacturing output rose 2 percent.)

During this period, growth in two of the industry's major markets, plastics and synthetic fibers, slowed. There were no comparable major new product markets to sustain high growth rates—rather, the organic chemicals industry had to seek new uses for old products. The increased cost of raw materials for petroleum-based chemicals, which led to increased final chemical prices, also depressed demand somewhat.[16] Furthermore, the industry faced increasing competition abroad (as the dollar strengthened) and at home (from foreign producers), especially in commodity chemicals. While the ratio of imports to new supplies (imports plus product shipments) remained fairly low—it was 0.034 in 1981 and 0.063 in 1985—increased imports in major end-use industries like automobiles and textiles dampened their output growth, thus indirectly reducing demand for the organic chemicals used by these industries.[17]

Table 2. Average annual rates of change in output for selected industries, 1963–85

Industry	1963–85	1963–74	1974–79	1979–85
All manufacturing	2.5	3.3	4.5	2.0
Industrial organic chemicals	5.0	8.4	5.9	−2.1
Selected industries:[1]				
Synthetic fibers	4.7	10.1	4.5	−2.7
Pharmaceutical preparations	5.1	8.4	4.2	0.4
Soaps and detergents	[2]2.9	4.6	2.5	−1.1
Cosmetics and other toiletries	[2]4.7	7.6	3.7	2.5
Paints and allied products	1.7	3.0	2.7	0.4
Tires and inner tubes	1.4	5.1	1.6	0.5
Miscellaneous plastics products	—	—	10.3	6.2
Major household appliances	2.1	3.6	5.9	0.3
Motor vehicles	2.8	4.2	8.3	5.2

[1] Major end-use markets for organic chemicals.
[2] 1963–84.

NOTE: Dashes indicate data not available.

Employment

Employment numbered 96,500 persons by 1985, having risen 13 percent since 1963, and having peaked at 117,200 in 1980. All of the long-term increase was among nonproduction workers, whose numbers rose 38 percent. The number of production workers was at its highest in 1979, that of nonproduction workers, in 1982.

From 1963 to 1969, moderate increases in employment occurred as salesforces were expanded to open up new markets.[18] (See table 3.) The period was followed by a 5-year lull, in spite of double-digit output increases in 1972, 1973, and 1974.

Nonproduction worker hours rose slightly faster from 1974 to 1979, as research and development efforts were stepped up to meet growing competition and to take advantage of new end-use markets—particularly in plastics. According to industry sources, a larger salesforce and clerical staff, many of whom had been hired in anticipation of continued high sales growth, were part of the nonproduction worker increase.[19] The rate of increase in production worker hours also rose.

Nonproduction worker hours declined from 1979 to 1985. Employment reductions, particularly in corporate staff, were made in conjunction with industrywide cost cuts.[20] The use of management information systems, on-line data base services that provide information on changing regulations and safety and health matters, and better training helped managers become more productive. In addition, some marketing departments increased their participation in industry marketing conferences at which they can present new products to many potential customers at one time, in lieu of numerous separate sales trips.[21] Both the number of production workers and their hours fell every year over the 1979–85 span, as some of the plants that had been closed on a temporary basis stayed closed.[22]

Occupations. Chemical engineers, chemists, and technicians account for a significant proportion of the professional workers employed. Two of the larger production worker occupational groups are machine operatives and mechanics, repairers, and installers.

The proportion of nonproduction workers is high in this industry, and increased from 34 percent in 1963 to 42 percent in 1985. This is 9 percentage points higher than the average for all manufacturing industries for 1963 and 12 points higher than that for 1985. As the use of instruments (especially when computer-based) and the complexity of equipment has grown, so has the need for highly skilled professionals.[23]

Technology, research, and capital

The technology employed to produce most organic chemicals, whether on a large scale or small, is based on chemical reactions: Feedstocks or intermediate chemicals (elements or compounds) are mixed with a catalyst under high pressure or high temperature, or both, in a tightly controlled environment to produce the desired chemical derivatives. Byproducts are separated and then recycled, processed further, sold, or otherwise disposed of.

Large-scale processes. Most commodity chemicals are manufactured in large-scale operations that have low labor requirements per unit of output. The plants that produce them usually operate 24 hours a day, 7 days a week. Such plants account for much of the industry's output volume. Computers control the complex chemical processes through feedback mechanisms that are monitored by engineers and other operators.

Although direct production unit labor requirements are low, there are some operations that are more labor intensive—repair and maintenance, and loading and shipping. Many hours are expended on checking and maintaining the miles of pipeline and other equipment, particularly during a turnaround (such as a scheduled maintenance shutdown), mothballing, or startup.[24] Repair and maintenance are crucial operations, because reactions take place under high temperature or pressure, or both, and often involve highly toxic or corrosive materials.

Olefin plants, which produce two of the major organic chemicals, ethylene and propylene, are large-volume producers. These plants are most economical when they produce great quantities; their annual capacity ranges upward of 1 billion pounds. In the early 1980's, more than 75 percent of the industry's ethylene capacity was from plants that could produce more than 500,000 metric tons annually. More than 20 percent was from plants with a capacity greater than 1 million metric tons.[25] Over the past 25 years, changes and refinements in the plants' processing technologies and increasing economies of scale led to a doubling of their average yield.[26]

Older olefin plants relied on natural gas-based raw materials (butane, ethane, and propane). These plants were succeeded by thermal or steam crackers which use naphtha and gas oil (or heavier, oil-derived hydrocarbons) as a feedstock. Olefin plants make ethylene, propylene (considered a coproduct), and other hydrocarbons, the proportions of which depend on the feedstock used. Generally, the lighter feedstocks produce higher percentages of ethylene.[27] During the early 1970's, many producers who were either retrofitting or building new plants switched from designs that used light hydrocarbon feedstocks to those using heavy hydrocarbons.

In the eighties, companies began to build plants that had more feedstock flexibility. Many new olefin plants were designed to handle wide variations in feedstock type, allowing for more rapid feedstock substitutions. However, use of alternate raw materials (other than the one(s) for which a plant is primarily designed) still result in lower product yield, higher costs, and less output.[28] But costly shutdowns, which had been required when switching feedstocks, can now generally be avoided.

These technological changes, though not primarily designed to lower unit labor requirements, have helped the industry improve productivity over the long run. Significant additional labor is required when starting up a plant or when greatly increasing output from a plant operating at very low capacity. But stepping up from 70 percent to 90 percent of capacity, for example, requires few additional production workers.[29] Continual, high-capacity operations facilitated by feedstock flexibility allow companies to use labor more efficiently.

One technological change that went hand in hand with the construction of very large plants during the seventies was the introduction of computers. (Although older plants were ofttimes retrofitted with state-of-the-art electronics, the new technology proved most effective in new plants.) Since then, there have been continual improvements in both computer hardware and software, particularly for process control. One recent innovation in this area has been the use of optimizing controls.[30] (Optimizing software, when employed plantwide, involves the use of extensive data bases, plant process models including economic and engineering variables and constraints, and reaction models, which all are then integrated with the control system.)

Overall, these changes have helped the industry produce a given volume of chemicals faster. Moreover, some processes are now so complex that they could not be run without computers. The computer control systems constantly monitor and collect data, and then calculate and evaluate the results. These data, in conjunction with process-specific software, enable the systems to perform automatic startups and shutdowns of process units, and to optimize on-line production under given conditions and constraints. Process controls also are used to analyze incoming raw materials and outgoing finished products. Controls have become so important that, in large plant

Table 3. Employment trends in the industrial organic chemicals industry, 1963–85[1]

Period	Average annual rates of change (in percent)		
	All employee hours	Production worker hours	Nonproduction worker hours
1963–1985	0.9	0.3	1.9
1963–74	1.7	1.3	2.5
1974–79	2.6	2.5	2.6
1979–85	−3.1	−4.0	−1.5

[1]The difference in rates of change between employment and hours was negligible over the long term, so only rates of change in hours are presented.

construction, instrument expense can account for up to 15 percent of total cost.[31]

Because most of these newer, large plants have very low labor requirements, only those technological innovations that make dramatic improvements in the feedstock-to-output ratio are likely to have a significant, if indirect, effect on labor productivity—and such changes are seldom felt industrywide, at least in the short term.[32] These process innovations can entail changing any or all of the factors in a chemical process—the required temperature or pressure, catalysts, raw material mix, reaction time, and so forth.

Specialty chemical plants. Specialty chemicals, such as synthetic perfumes, are often produced in small volume, either on a batch basis or in a continuous process. While a few stock specialty chemicals are made in quantity, most are custom ordered and produced in short runs. An average specialty plant produces 50 or so different chemicals. In general, these processes tend to be labor intensive, particularly the batch processes. However, recent technological improvements, largely in computerized process controls, have led to increased automation. These advances are particularly applicable to continuous operations, although it is possible to automate some parts of batch processes.

Research and development. Research is crucial to this industry as it seeks to meet the changing user needs. The research and development budgets for all chemicals companies (as a percent of sales) run 15 percent to 20 percent above the all-industry average.[33]

Much of the research focuses on existing products and processes, resulting in incremental improvements. Some of the research is directed toward end-product development, though in recent years it has seldom resulted in revolutionary new products. Instead, research has led to the development of new markets or new applications for existing products.

There is also continual research on technology, though it is focused on improving labor productivity to only a limited degree. Through replacement or retrofitting, plant equipment may be adapted to shifts in raw materials markets (based on price and availability); to new chemical processes that are more energy efficient, have higher yields, and so forth; and to cope with new environmental or safety hazards and regulations. The energy crisis of the seventies made feedstock flexibility and energy efficiency particularly important. New catalysts which are effective at lower temperatures are examples of technological change used to increase energy efficiency.

Capital investment. For the industry as a whole, large expenditures are needed each year to maintain equipment and structures because of the huge amount of capital stock in place. In 1982, capital assets per employee were almost six times greater than for all manufacturing.[34] In addition, because technological changes in this industry occur more or less continuously, obsolescence is rapid and high rates of depreciation are common.[35] In the past, the industry's plant and equipment had a comparatively short lifespan owing to the pace of technological change, the rapidly increasing economies of scale, and the corrosive, high pressure, high temperature processing environment. The average life span of plants lengthened somewhat after 1973 as the pace of technological change slowed and fewer replacement plants were built. (By that time, near-maximum economies of scale had been reached for some commodities and the cost of new plants had risen sharply.[36])

Online industry capacity for a given chemical changes periodically. Within the total available capacity for a product, actual online capacity is adjusted to fluctuations in supply and demand by closing and opening the small, older plants. In addition, plants regularly shut down as they undergo extended turnarounds during which equipment and catalysts are checked and serviced, and, at times, complete processes are replaced.

Industry structure. In 1982, 74 percent of the establishments in the industry had fewer than 100 employees—only 3 percent had 1,000 workers or more. The group of small plants accounted for 10 percent of industry value of shipments and 11 percent of employees. In contrast, the large establishments produced 44 percent of total shipments and employed 45 percent of the industry work force.[37]

Because of the interdependence in the industry (that is, the end product of one plant may be the feedstock of another), many plants intentionally are located near one another. For example, plants making methanol may be integrated with plants making ammonia because the processes and ancillary equipment are similar and the production of methanol requires carbon dioxide, which is a byproduct of ammonia synthesis.

Outlook

The organic chemicals industry has undergone extensive restructuring in recent years, as it undertook a major upgrading of its plants (while restricting capacity expansion), consolidated product lines, closed or sold off inefficient plants, and trimmed its labor force.[38] These changes have possibly laid the foundation for long-term productivity increases, if output grows steadily. The areas of potential output growth appear to be changing, however. Chemicals companies are focusing on opportunities for growth in specialty chemicals because it is unlikely that the commodity chemicals portion of the industry will experience many large, long-term output increases. Octane enhancers and methanol fuels are two of the few potential high-growth areas for commodities. U.S. companies may find it increasingly less expensive to import feedstock chemicals, rather than produce their own. These imports will come largely from increased production in the Middle East, Mexico, Canada, and other countries that have ready access to cheap and plentiful supplies of oil and natural gas.

Technological innovation for commodity chemical processing will continue, but probably at the comparatively slow rates of recent years. There is greater potential for productivity improvement in specialty chemical production. If research and development activities continue to intensify and efforts to automate batch or semicontinuous processes typical of specialty chemical production are sustained, significant productivity improvements may result. □

FOOTNOTES

[1] The segment of the organic chemicals industry discussed in this article, SIC 2869, is defined in the *1972 Standard Industrial Classification Manual* as including establishments primarily engaged in manufacturing industrial organic chemicals not elsewhere classified. Important products of this industry include: noncyclic organic chemicals; solvents; polyhydric alcohols; synthetic perfume and flavoring materials; rubber processing chemicals; plasticizers; synthetic tanning agents; chemical warfare gas; and esters, amines, etc. of polyhydric alcohols and fatty and other acids.

Average annual rates of change presented in this article are based on linear least squares of the logarithms of the index numbers. Extensions of the indexes will appear in the annual BLS Bulletin, *Productivity Measures for Selected Industries and Government Services.*

[2] Martin Neil Baily and Alok K. Chakrabarti, "Innovation and Productivity, in U.S. Industry," *Brookings Papers on Economic Activity,* 2, 1985, pp. 611, 619. The average number of product innovations per year in the chemical industry was as follows:

	Radical or major differences	*Significant improvement*	*Minor importance*
1967–73	2.4	96.9	232.6
1974–79	.2	9.0	29.7
1980–82	.0	5.7	59.0

[3] Industry sources; Harold A. Wittcoff and Bryan G. Reuben, *Industrial Organic Chemicals in Perspective, Pt. One: Raw Materials and Manufacture* (New York, John Wiley & Sons, 1980), p. 20; and various issues of U.S. Department of Commerce, *U.S. Industrial Outlook* (Washington, Government Printing Office), chapters on chemicals.

[4] Industry sources; Baily and Chakrabarti, "Innovation and Productivity," pp. 615, 624; and U.S. Department of Commerce, *1982 U.S. Industrial Outlook,* p. 98.

[5] Effective or preferred capacity is lower than full capacity due to cost considerations or other reasons. Capacity rates quoted are from various issues of the American Chemical Society's *Chemical & Engineering News* and the *U.S. Industrial Outlook.*

Many of the references to energy usage and capacity utilization refer to the "petrochemical" industry or the "organic chemical" industry because data at the 4-digit level are not available. In 1984, SIC 2869 accounted for 79 percent of total employment and 81 percent of the overall value of shipments in SIC 286, Industrial Organic Chemicals. The petrochemicals group includes the following industries: 2821, 2822, 2824, 2843, 2865, 2869, 2873, and 2895. Of these, SIC 2869 is the largest.

[6] Baily and Chakrabarti, "Innovation and Productivity," pp. 617–18, 623. Employees of two large commodity chemical producers, who were interviewed in conjunction with this study, confirmed that a falloff in innovation and the slowdown in product demand were two of the most important causes of the productivity slowdown.

The following data on the average number of process innovations per year were presented on this study of the total chemical industry:

	Productivity-enhancing innovations			*All process innovations*		
	Major	*Significant*	*Minor*	*Major*	*Significant*	*Minor*
1967–73 ...	0.6	4.1	2.6	3.1	22.7	13.1
1974–79 ...	.3	2.8	1.0	2.7	15.8	13.8
1980–82 ...	.7	5.7	1.0	2.3	23.7	8.7

[7] Richard C. Levin, "Technical Change and Optimal Scale; Some Evidence and Implications," *Southern Economic Journal* (Southern Economic Association and the University of North Carolina at Chapel Hill, October 1977), p. 214; and Baily and Chakrabarti, "Innovation and Productivity," pp. 623, 630.

[8] Industry sources; and Baily and Chakrabarti, "Innovation and Productivity," p. 624.

[9] Wittcoff and Reuben, *Industrial Organic Chemicals in Perspective, Pt. One: Raw Materials and Manufacture,* p. 20; Jane H. Cutaia, "Rediscovering the formula for profits," *Business Week,* Jan. 12, 1987, p. 72; and Baily and Chakrabarti, "Innovation and Productivity," p. 624.

[10] Industry sources.

[11] "Productivity makes slim gain as capacity use remains low," *Chemical & Engineering News,* June 14, 1982, p. 61.

[12] Ted Wett, "Capacity down, production up: Rx for ethylene's '84 outlook," *Oil & Gas Journal,* Sept. 3, 1984, p. 55; and U.S. Department of Commerce, *1983 U.S. Industrial Outlook,* pp. 9–7, 9–9.

[13] *Chemical and Engineering News,* Apr. 13, 1987, p. 21.

[14] U.S. Department of Commerce, Industry and Trade Administration, *1985 U.S. Industrial Outlook* (Government Printing Office, January 1985), p. 11–2.

[15] Chemical-grade olefins, particularly ethylene and propylene, are among the most important feedstocks for organic chemicals. These olefins are made from either natural gas or naptha fractions, which are petroleum-based.

[16] Baily and Chakrabarti, "Innovation and Productivity," p. 623.

[17] Bernard A. Gelb and Gary L. Guenther, *U.S. Primary Petrochemicals: The Superfund Taxes and Other Factors Shaping Recent Trends in Supply and Demand* (Washington, Congressional Research Services, The Library of Congress, Aug. 30, 1984), pp. 12, 15–17, 21–23; and Bailey and Chakrabarti, "Innovation and Productivity," pp. 623–24.

[18] Industry sources.

[19] Industry sources; and Baily and Chakrabarti. "Innovation and Productivity," p. 624.

[20] Industry sources; and U.S. Department of Commerce, *1983 U.S. Industrial Outlook,* p. 9–7.

[21] Industry sources.

[22] Industry sources; and U.S. Department of Commerce, *1983 U.S. Industrial Outlook,* pp. 9–10 to 9–12.

[23]R. Norris Shreve and Joseph A. Brink, *Chemical Process Economics* (New York, McGraw-Hill, 1977), p. 20.

[24]Industry sources.

[25]U.S. Department of Commerce, *1983 U.S. Industrial Outlook,* p.9–9.

[26]Wittcoff and Reuben, *Industrial Organic Chemicals in Perspective, Pt. One,* p. 35.

[27]Plants produce different grade feedstocks; chemical (95 percent C_3) or polymer grade (99.9 percent C_3) determines whether they will be used further within the industry (perhaps captively), or sold as a commodity to other industries. (Refinery grade chemicals are made largely by those olefin plants in the petroleum refining industry.)

[28]U.S. Department of Commerce, *1983 U.S. Industrial Outlook,* p. 9–8.

[29]Industry sources.

[30]Industry sources; G. L. Funk and C. C. Kania, "Optimizing an entire olefins plant pays off," *Oil and Gas Journal,* Sept. 3, 1984, p.75; and Shreve and Brink, *Chemical Process Economics,* pp. 12–16.

[31]Shreve and Brink, *Chemical Process Economics,* p. 12.

[32]The average number of production workers per plant in 1982 was only 94.

[33]John K. Stille, *Industrial Organic Chemistry* (Englewood Cliffs, NJ, Prentice-Hall, 1968), p. 1; and Wittcoff and Reuben, *Industrial Organic Chemicals in Perspective, Pt. One,* p. 20.

The following data on research and development expenditures for SIC 28 are from the Bureau of the Census, *Statistical Abstract of the United States 1986* (Government Printing Office, 1985), p. 580:

	R&D dollars (millions)	*R&D as a percent of sales*	
Year	*SIC 28*	*SIC 28*	*All industries*
1975	$2,727	3.7	3.1
1980	4,636	3.6	3.0
1983	7,287	4.4	3.8

According to 1981 data from the National Science Foundation, the industrial chemical industry (SIC 281,2,6) spends slightly less on research and development than the total chemical industry (2.7 versus 3.0 percent of research and development to value of shipments).

[34]Bureau of the Census, *1983 Annual Survey of Manufactures,* M83(AS)4 (Government Printing Office, 1986), pp. 4–7, 4–31.

[35]Stille, *Industrial Organic Chemistry,* p. 1.

[36]Wittcoff and Reuben, *Industrial Organic Chemicals in Perspective, Pt. One,* pp. 1, 27.

[37]Bureau of the Census, *1982 Census of Manufactures,* MC82-I-28F (Government Printing Office, 1985), p. 28F–9.

[38]Blanca Riemer, "Are America's manufacturers finally back on the map?" *Business Week,* Nov. 17, 1986, pp. 92–93; Jane H. Cutaia, *Business Week,* Jan. 2, 1987, p. 72; and "Chemical Recovery Follows Restructuring," *Chemical Marketing Reporter,* Dec. 15, 1986, p. 3.

APPENDIX: Measurement techniques and limitations

Indexes of output per employee hour measure changes in the relation between the output of an industry and the employee hours expended on that output. An index of output per employee hour is derived by dividing an index of output by an index of industry employee hours.

Real output was calculated in terms of the deflated value of shipments (adjusted for inventory change) for each product group. Changes in prices were removed from the current-dollar values by means of appropriate price indexes at various levels of subaggregation for a variety of products in each group. In order to combine the output segments into a total output index, employee hour weights relating to the individual segments were applied.

Complete output data are available only in years for which the Commerce Department takes a Census of Manufactures (such as 1972, 1977, and 1982). For the intercensal years, the data are based on samples, and are not quite so complete. Therefore, these data are benchmarked to census-year data.

The indexes of output per employee hour relate total output to one input—labor. The indexes do not measure the specific contribution of labor, capital, or any other single factor. Rather, they reflect the joint effects of factors such as changes in technology, capital investment, capacity utilization, plant design and layout, skill and efforts of the work force, managerial ability, and other factors.