Productivity in crude oil and natural gas production

In 1959–90, labor productivity declined in the production of crude oil and natural gas, as U.S. oil fields aged

Brian L. Friedman

Productivity (as measured by output per employee hour) in the crude petroleum and natural gas production industry declined at an average annual rate of 1.1 percent from 1959 to 1990.[1] (See table 1.) Productivity growth was hampered by increasingly difficult access to new oil and gas supplies over the period. Productivity was also strongly affected by the volatile rise and fall of the price of oil and related products, which influenced the economic feasibility of employing more marginal and labor-intensive types of recovery. Productivity declined during the period as labor increased in times of high prices, while output growth was slowed by diminishing reservoir pressure in existing oil fields.

There were three distinct periods of economic activity that produced different productivity trends during 1959–90: 1959–72, a period of increasing production and low prices; 1972–82, a period of declining production despite the incentives of high world oil prices and technological advances; and 1982–90, a period of predominantly declining prices and continued declining production. The following tabulation lists the average annual rates of change for three productivity-related variables during the three separate subperiods of the period under study:

	Annual percent change			
	1959–72	*1972–82*	*1982–90*	*1959–90*
Output per hour	5.4	–7.8	3.6	–1.1
Output	3.4	–.9	–1.2	.3
Employee hours	–1.9	7.4	–4.7	1.5

Brian L. Friedman is an economist in the Division of Industry Productivity and Technology Studies, Bureau of Labor Statistics.

Productivity trends

From 1959 to 1972, U.S. oil and gas production was growing at an average annual rate of 3.4 percent, as the addition of newly found oil reserves exceeded the depletion of existing reserves. In general, the number of stripper oil wells declined during the period.[2] Stripper wells are oil wells that produce 10 or fewer barrels of oil per day. The low price of oil made it only marginally economically feasible to keep these wells in production. There was also little incentive to employ more sophisticated, expensive, and labor-intensive production techniques for recovering oil. Employment declined steadily at a rate of 1.9 percent per year, and output per hour rose at a rate of 5.4 percent per year.

U.S. production of gas and oil, however, peaked in the early 1970's. U.S. consumption became increasingly dependent on foreign supplies, which led to two shocks to industry prices. The OPEC oil embargo occurred during 1973–74 and caused world oil prices to rise significantly. Then, the cutbacks in Iranian oil production in 1979 led to another round of rapid price increases. During 1972–82, world oil prices quadrupled.

Increasing prices led to greatly increased U.S. industry activity in exploration and production during 1972–82. Crude oil, however, had become harder to find and harder to produce than in earlier years. The number of marginal stripper wells rose substantially. Increases in enhanced oil recovery production techniques and technological innovations helped mitigate production declines that, nevertheless, reached 0.9

percent per year. Industry employment, however, rose 7.2 percent per year, and output per hour fell at an annual rate of 7.8 percent.

The most recent period, 1982–90, was generally a period of oversupply of foreign crude oil and declining prices. Oil prices fell very rapidly in 1986. Some of the more expensive and labor-intensive production techniques lost their economic feasibility.[3] The number of stripper wells, which had been growing since 1970, fell by nearly 9,000 in 1987.[4] Industry output continued to fall 1.2 percent per year, but employment fell 4.7 percent annually. The industry shrank in size, but what remained were, by and large, the most efficient wells, with the best equipment, run by the most experienced personnel.[5] Output per hour increased at a rate of 3.6 percent per year.

Oil prices began to rise again in 1989. The confrontation with Iraq, beginning in August of 1990, marks the end of this period, with prices climbing toward the levels of the early 1980's. The very large employment declines of 1986 and 1987 were replaced by very small employment declines in 1989 and 1990. Productivity declined in these 2 years after 5 years of posting gains.

Output

In 1960, natural gas and petroleum products accounted for nearly 74 percent of all U.S. energy consumption. By 1970, this percentage had grown to more than 77 percent. Increasing prices following the OPEC oil embargo spurred energy conservation efforts in the United States. Automobiles that provided better gasoline mileage, lower speed limits, and the switching of many utilities to coal lowered the amounts of industry products used as a percentage of total energy consumed. Still, natural gas and petroleum products accounted for nearly 65 percent of all U. S. energy consumed in 1990.[6]

Table 1. **Indexes of output per employee hour and related data, crude oil and natural gas (SIC 1311), 1959–90**

[1982 = 100]

Year	Output per employee hour	Output per employee	Output	All employees	All employee hours
1959	116.5	116.2	78.9	67.9	67.7
1960	123.0	122.1	79.7	65.3	64.8
1961	130.6	129.9	81.6	62.8	62.5
1962	136.9	136.5	83.8	61.4	61.2
1963	144.4	144.7	86.8	60.0	60.1
1964	150.6	150.3	88.4	58.8	58.7
1965	158.7	158.2	90.8	57.4	57.2
1966	173.8	173.2	96.8	55.9	55.7
1967	187.9	186.9	102.6	54.9	54.6
1968	197.6	196.5	106.7	54.3	54.0
1969	205.8	205.4	109.7	53.4	53.3
1970	217.4	216.2	114.8	53.1	52.8
1971	214.9	214.5	113.9	53.1	53.0
1972	216.3	216.8	113.8	52.5	52.6
1973	222.9	219.4	111.9	51.0	50.2
1974	207.4	201.5	106.6	52.9	51.4
1975	183.3	177.5	101.0	56.9	55.1
1976	169.3	167.0	98.7	59.1	58.3
1977	160.5	160.2	99.8	62.3	62.2
1978	153.8	154.0	103.2	67.0	67.1
1979	141.7	141.5	102.9	72.7	72.6
1980	125.1	124.5	102.8	82.6	82.2
1981	106.8	106.8	102.1	95.6	95.6
1982	100.0	100.0	100.0	100.0	100.0
1983	99.2	100.2	97.2	97.0	98.0
1984	105.0	105.9	101.2	95.6	96.4
1985	106.9	107.8	100.1	92.9	93.6
1986	116.4	118.1	97.1	82.2	83.4
1987	128.0	127.5	95.6	75.0	74.7
1988	128.9	128.9	95.1	73.8	73.8
1989	125.1	126.4	91.8	72.6	73.4
1990	123.4	125.4	90.3	72.0	73.2
	Average annual rates of change				
1959–90	–1.1	–1.1	0.3	1.4	1.5
1985–90	2.7	2.8	–1.9	–4.6	–4.5

Industry products are widely used in the transportation and industrial sectors. Gasoline accounts for around 40 percent of the use of refined petroleum. In 1990, petroleum products and natural gas each accounted for 37 percent of industrial energy consumption.[7] Petroleum products are also used for nonfuel purposes, such as asphalt, road oil, lubricants, and petrochemical feedstocks. Natural gas is the primary source for heating households.[8]

The production of crude oil and that of natural gas are interrelated. Crude oil and natural gas are found in deposits close to each other or mixed together. Natural gas is often produced along with crude oil, with 20 to 25 percent of all natural gas produced from oil wells. Lease condensate—liquid hydrocarbons that are removed from natural gas at the well site—are also produced by the industry.

During the first 10 years of the study period, crude oil production capacity exceeded demand. Import ceilings were used to protect the domestic industry.[9] Crude oil production rose from 7.05 million barrels a day in 1959 to a high of 9.64 million barrels per day in 1971. By the early 1970's, demand had increased to the point where crude oil production was at 100 percent of capacity.[10] Gas production grew from 12.05 trillion cubic feet in 1959 to a high of 22.65 trillion cubic feet in 1973.

Crude oil production began to decline in the early 1970's. Much of the decline was the result of diminishing reservoir pressure in existing oil fields, combined with low levels of exploration for new oil in the 1960's. Crude oil production declined during 7 years of the 1970's. Production leveled out in the early 1980's, due in part to increases in exploration in the late 1970's and in part to increases in the number of new developmental wells and older stripper wells producing on existing oil fields. World surpluses of crude oil in late 1985 and 1986, however, caused sharp declines in oil prices. U.S. production began falling again in 1986 and continued to decline throughout the rest of the decade.[11]

Production of natural gas was less influenced by world markets than was crude oil because of domestic price regulation and the difficulty in transporting and importing gas. Natural gas was relatively cheap and preferred for environmental reasons. Production increased every year from 1959 to 1973. Low controlled prices, however, led to low natural gas reserves. In 1978, the Natural Gas Policy Act was enacted. The Act was designed to remove price controls gradually and stimulate production. This, coupled with declining demand, led to an oversupply of gas in the early 1980's.[12] The oversupply was also due, in part, to the steady production of gas from oil wells that were producing at full capacity, despite declining demand in natural gas markets.[13] Production from pure gas wells declined sharply in the early 1980's.

Total industry output of combined oil and natural gas declined during 7 years of the 1970's and every year of the 1980's except 1984. By 1990, industry output had declined from its high in 1970 to levels slightly below those of 1965.

Employment and hours

The trends for employment and hours show little relationship to output, but a very direct relationship to the price of oil. Whenever the price of oil increased, employment increased in an attempt to produce more oil in times of high prices. (See chart 1.)

The relationship between the price of oil and employment was a key factor influencing productivity trends in the industry. Productivity declines were largely the result of the influx of employees and hours into the industry during periods of rapidly rising oil prices. It became economically feasible to hire more employees, even though increases in output were only marginal. In addition, more small companies entered the industry during times of high prices.[14] With overall production relatively flat, productivity trends were inversely related to employment trends. (See chart 2.)

Employee hours actually declined from 1959 to 1972 at an average annual rate of 1.9 percent as prices for gas and oil increased at a rate of only 1.3 percent per year. During this period, the slow growth in price provided little incentive for the industry to increase employment. Employee hours, however, rose at an average annual rate of 7.4 percent from 1972 to 1982 as the price of oil rose 23.6 percent per year. The rapid average annual decline in price (7.5 percent) from 1982 to 1989 was associated with an average annual decline of 5.2 percent in employee hours.

There is a very high proportion of nonproduction workers in the crude petroleum and natural gas production industry relative to other mining industries. This is because most of the production workers associated with drilling and geophysical exploration are contracted from the oil field services industries, SIC 138. For the crude petroleum and natural gas industry (SIC 1311), nonproduction workers grew from 36.5 percent of industry employment in 1959 to 48.3 percent in 1969. The proportion has remained at approximately 50 percent since, with a low of 48.2 percent in 1971 and a high of 56.3 percent in 1981.

The nonproduction workers within the industry include engineers, computer specialists, mathematicians, and physical scientists. There are also large numbers of administrative and clerical personnel, as well as lawyers and others involved in purchasing potential oil-producing properties. In addition, the central administrative and auxiliary offices support a large amount of research affecting the entire oil industry. Production workers within the industry are for the most part hoist operators, mechanics, painters, pumpers, roustabouts, truck drivers, welders, and well-service personnel.

Factors affecting productivity

Aging fields. Productivity growth during the 1970's and 1980's was adversely affected by oil and gas being increasingly harder to find. There is typically a 5- to 7-year lag from the beginning of exploratory expenditures to substantial production gains.[15] The rapidly rising and falling price of oil was outside the control of the domestic industry. The uncertainty over future oil prices led to an increasing dependence on existing oil fields.[16] Some of the increased drilling activity during 1972–82 was exploratory drilling. While the number of exploratory oil wells increased every year during this period,[17] proven reserves continued to decrease every year.[18] Most of the oil wells drilled during 1972–82 were development wells, designed to increase production from already discovered fields. This type of well nearly quadrupled in number.[19]

The production capacity of existing oil fields was at its highest in the 1960's and began to decline in the early 1970's.[20] The proportion of oil wells requiring artificial lift, or mechanical pumping, began increasing in the mid-1960's and gradually increased through the 1980's.[21] Average oil well production per day, which grew steadily since 1959, reached a peak in 1972 and began a gradual decline that continued throughout the 1970's and 1980's.

Average gas well production reached a peak in 1971 and began a steady and much steeper decline than did average oil well production. In 1990, the average gas well produced only 38 percent per day as much as the average gas well did in 1971.[22] Some of this downturn was in response to oversupply and came from intentional cutbacks in production, beginning in early 1982 and lasting throughout the decade.[23]

Chart 1. Some trends in the crude oil and natural gas industry, SIC 1311, 1959–90

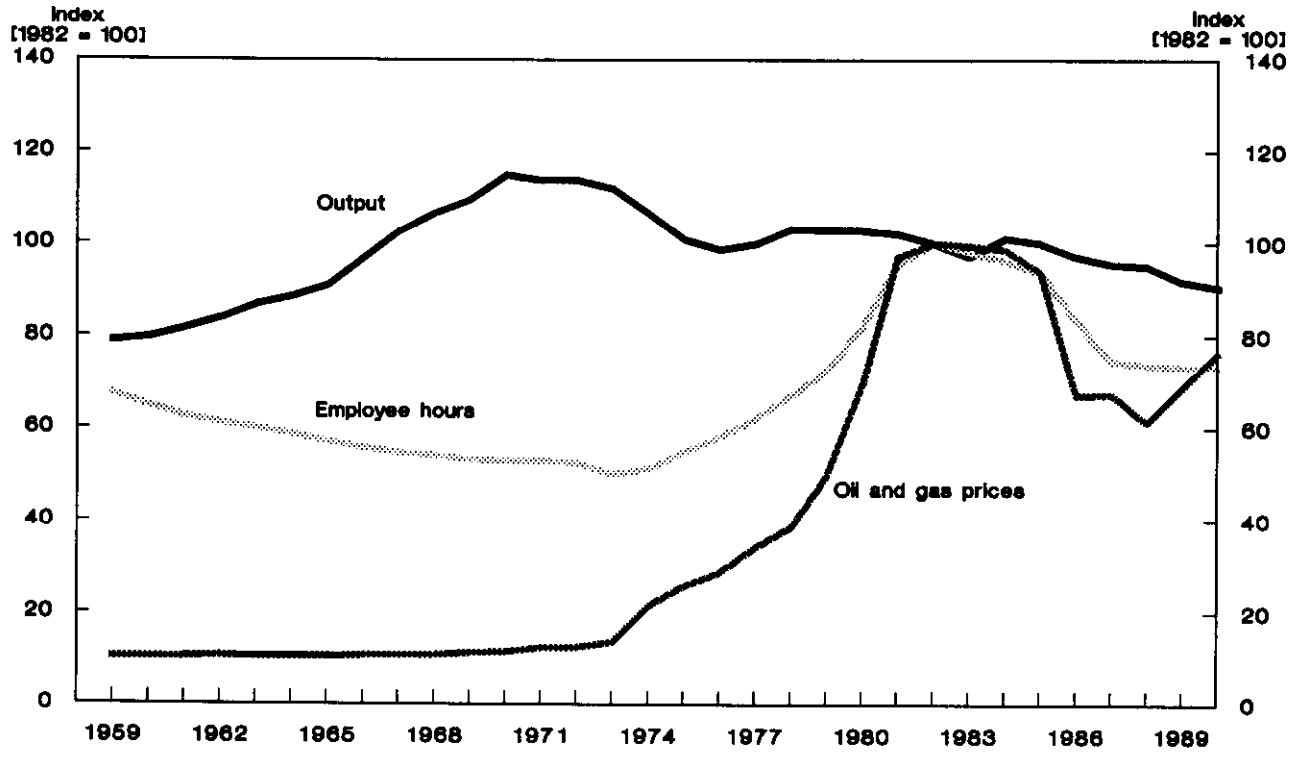
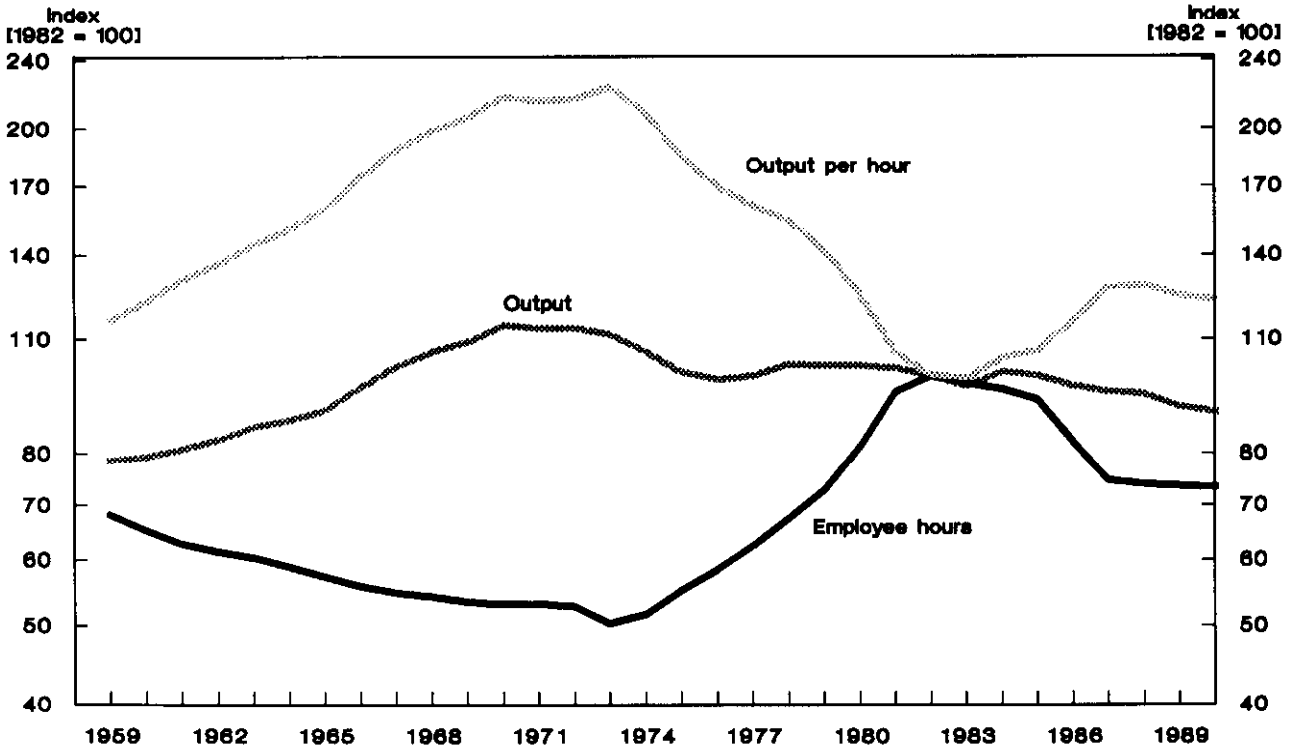


Chart 2. Productivity and related measures in the crude oil and natural gas industry, SIC 1311, 1959-90



Stripper well production. In 1959, 67.3 percent of all oil wells were stripper wells, and they provided 20.7 percent of all U.S. oil production in that year. In 1986, before the large drop in world oil prices, 73.2 percent of all producing oil wells were stripper wells, but they only accounted for 14.5 percent of U.S. crude oil production. Average daily production per well fell from a high of 4.0 barrels in 1961 to only 2.3 barrels in 1990.[24]

The economic feasibility of having these marginally producing wells in production depends on price levels. There is an inverse relationship between the growth of stripper wells and productivity growth. The number of strippers fell during the 1960's, which was a period of rising productivity, and increased in the 1970's, when productivity declined. Similarly, stripper gas wells were increasingly taken out of production during the 1980's, while productivity growth was again rising.[25]

Capital expenditures. Capital expenditures in the crude petroleum and natural gas industry (SIC 1311) equaled 22.3 percent of industry shipments in 1963. Expenditures increased to 26.7 percent in 1977 and 25.4 percent in 1982; then they fell to only 13.7 percent of shipments in 1987. Capital outlays per employee grew from $15,200 in 1963 to a high of $129,800 in 1982 and far exceeded mining industry averages.[26]

The bulk of capital expenditures in the industry are for mineral exploration and development. These outlays include expenses for supplies, machinery, fuel, and parts in the exploration and development of any potential or working oil- or gas-producing property. They also include some costs for labor, which can be contract labor or industry employees. Exploration and development expenditures grew from a low of 54.0 percent of capital costs in 1967 to a high of 77.4 percent of capital costs in 1982. In 1987, exploration and development costs had fallen to 62.3 percent of capital expenditures.[27]

Land costs and mineral rights expenses for the entire industry are excluded from available data on capital expenditures. Data for 30 large energy companies show that, for 1982, domestic outlays for the acquisition of potential petroleum-producing properties were $7.9 billion.[28] Expenditures for environmental protection have increased significantly since the mid-1960's.[29] The high costs for land and environmental protection have been a factor affecting exploration and production.[30]

Structure. The largest companies within SIC 1311 produce the bulk of industry output. Major oil companies, with huge oil and gas fields, dominate the industry. Offshore drilling and production are especially dominated by major oil companies. The 20 largest oil companies account for 75 percent of all offshore capital expenditures.[31]

In 1963, the 16 largest companies accounted for only 3.8 percent of establishments (producing oil or gas fields), but had 58.6 percent of industry value of shipments, 46.8 percent of employment, and 62 percent of industry capital expenditures. In 1972, when industry activity was slowing down, the 16 largest companies accounted for 5.8 percent of establishments, 69.9 percent of shipments, 32.2 percent of employment, and 60.7 percent of capital expenditures. By 1982, just past the peak in industry activity, the top 16 companies accounted for 14.5 percent of establishments, 56.4 percent of shipments, 39.7 percent of employment, and 56.1 percent of capital expenditures.[32]

Nevertheless, there are a large number of companies and establishments in SIC 1311. As many as 50 oil companies are vertically integrated.[33] In all, there were 8,676 companies operating 12,087 establishments in 1982.

Technology. There have been numerous small innovations and improvements to existing technologies in oil and gas field production. Many of these involve the basic sucker rod pumping systems in oil wells and shutoff systems necessary for maintenance of both oil and gas wells.[34] There have also been improvements in steel metallurgy that have allowed the production of deep, high-temperature, sulfurous natural gas.[35]

Large increases in offshore technological developments occurred during the late 1970's and early 1980's.[36] Submersible production systems for offshore wells and special equipment for use in arctic climates made it possible to exploit previously inaccessible oil and gas fields. Although these technologies aid output growth, their effect on productivity is uncertain. Innovations, however, have helped the industry offset some of the problems and costs involved in producing oil and gas under more difficult circumstances.[37]

One technology that has had a positive influence on productivity has been the computer. The use of personal computers to deal with bookkeeping duties is widespread in the industry. In the field, computers quickly measure the flow of natural gas and monitor liquid flow from oil wells.[38] In 1973, computers were used for field management in 82 percent of Exxon's oil production. Exxon estimated then that these computers improved production by 5,000 barrels per day.[39]

Integrated computer software used on personal computers employs historical well production statistics as a data base to estimate reserves and analyze deliverability and declines in production. The software is a great timesaver in these types of analysis.[40]

Programmable logic controllers are a digital electronic apparatus with programmable memory that controls machines and processes. Developed in the auto industry and introduced into the oil industry in the middle 1980's, they first saw use in the industry on offshore platforms as replacements for pneumatic systems that regulated and set the pressure of fluids in separators. They are considered safer than the systems they superseded and replace very labor-intensive operations. In some instances, they are used to control virtually all offshore platform processes. They are also used onshore, where they are considered valuable in saving training time and in simplifying troubleshooting and spare part requirements. Programmable logic controllers can be applied to whole field operations to reduce labor requirements.[41]

Enhanced oil recovery. In primary recovery from an oil well, the natural water and gas pressure of the reservoir is used to bring the oil to the surface. When the natural pressure declines, primary production also includes artificial lift. In secondary recovery, which is commonly used, water, or sometimes natural gas, is pumped down injection wells to force oil to the surface. Primary recovery and secondary recovery usually bring 30–50 percent of the recoverable reserve into production.[42] Tertiary production, known as enhanced oil recovery, is used to bring as much of the rest of the reserve as is possible to the surface.

Enhanced oil recovery is complicated and expensive. Steam, heat, chemicals, or gas is injected into the reservoir to repressurize it or to change the viscosity of the crude oil in it. Enhanced oil recovery can add up to 10 years to the productive life of an oil field.[43]

Rising prices made increases in the use of enhanced oil recovery economically feasible in the late 1970's. The number of projects in which carbon dioxide was flooded into reservoirs increased from 20 in 1980 to 100 in 1986. Also in 1986, there were 200 thermal projects and 200 chemical projects. That year, enhanced oil recovery accounted for 605,000 barrels of crude oil per day, until falling prices halted the growth in the use of these technologies.[44] By 1989, enhanced oil recovery was down to producing 500,000 barrels daily.[45] By 1990, however, with

prices rising, oil produced by these methods was up to 700,000 barrels per day.[46]

Enhanced oil recovery is more labor intensive than primary and secondary recovery. Although it increases production, it also usually increases unit labor requirements.[47] In times of high prices, enhanced oil recovery can contribute to declines in labor productivity.

Unconventional gas recovery is less developed than enhanced oil recovery, yet it is considered important to the future recovery of natural gas reserves.[48] The technique is used mostly for tight sand formations where large amounts of gas are trapped in individual small pockets. Hydraulic fracturing is most commonly used to release the gas. Fracture methods are also used to recover gas from the methane seams of coalbeds and from Devonian shale formations. Some forms of fracturing have become standard enough to no longer be considered unconventional. Unconventional gas recovery is generally slower than primary gas recovery, and many techniques are not economically feasible at current price levels.[49] The increased usage of unconventional gas recovery, with current technology, would tend to dampen labor productivity growth.

Outlook

The basic dynamics that have influenced the crude petroleum and natural gas industry for the past two decades will continue to mold production and productivity growth in the foreseeable future. Lower prices depress the domestic industry and stimulate demand, while foreign producers gain market share. Higher prices stimulate the domestic industry. In order to sustain long-term investment and production, a portion of the domestic industry prefers guaranteed price levels.[50] If increasing prices lead to increased production from new oil and gas reservoirs, productivity growth will be affected positively. If, however, increasing prices only increase marginal production, productivity growth will be affected negatively.

Production from existing U.S. oil fields is declining. In the lower 48 States, this decline has been continuing since 1970. Production from existing Alaskan oil fields has also begun to decline and is expected to fall sharply in the future. Offshore production is expected to decrease as well.[51] In addition, there has been a shift away from domestic investment for exploration to international projects, because of more favorable success rates of wildcatting outside the United States and because foreign governments provide incentives to encourage exploration.[52] Even if major reservoirs are found in the continental United States, there is a shortage of labor from the prolonged industry downturn in the 1980's. Both skilled production workers and professional employees have moved on to other industries.[53]

Future U.S. production and productivity will be affected by new technology. Horizontal drilling is expected to add significant new recoverable reserves for U.S. production.[54] Recent technological advances involving undersea equipment may make some previously marginal offshore sites economically feasible for production.[55] Improvements in enhanced oil recovery, even in the use of microbial techniques, will help future production if the price of oil increases enough to make the techniques profitable.[56] The Gas Research Institute estimates that 16 percent of natural gas production from the lower 48 States by the year 2000 and 42 percent by the year 2010 will be produced using new technology.[57] The total impact of these developments on productivity, however, remains uncertain.

Domestically, future production and productivity trends are clouded by environmental considerations. Opposition to offshore drilling is strong, especially in California, where there are thought to be large untapped offshore reserves.[58] Similarly, the exploration and development of large reserves in the Arctic National Wildlife Refuge in Alaska are being opposed by environmental groups.

The enormous investment in both time and money that is necessary for the growth of the domestic oil and gas industry requires a stable environment and stable oil prices. The international and domestic political forces that affect the U.S. oil and gas industry are extremely complex. The uncertainties produced by these complex political forces have led to basic disagreements concerning a national energy strategy. It is likely that the industry will be cautious in initiating large investments in domestic exploration and production in the face of so much uncertainty. □

Footnotes

[1] The crude petroleum and natural gas industry (SIC 1311) includes establishments engaged primarily in operating oil and gas fields and related properties. There are some drilling and geophysical exploration activities encompassed by SIC 1311, but these activities generally involve less than 10 percent of industry production workers. The results of these activities, in terms of feet drilled or new reserves found, are considered intermediate outputs to the oil and gas produced. The productivity and related measures for SIC 1311 are intended to measure only oil

and gas production, and not exploration and drilling activity, in the U.S. oil industry. The great majority of exploration and drilling activity in the U.S. oil industry is done by employees from SIC 138, oil and gas services, which are not included in the measures of productivity and employment presented in this article.

The average annual rates of change reported here are based on the linear least squares trend of the logarithms of the index numbers. Extensions of the indexes will appear in the annual Bureau of Labor Statistics bulletin, *Productivity Measures for Selected Industries and Government Services*.

[2] National Stripper Well Survey, *Basic Petroleum Data Book*, American Petroleum Institute, May 1990, section IV, table 3.

[3] Scott L. Weeden, "Miscible Flood EOR Can Unlock Multi-Billion Barrel Reservoirs in U.S., Canada, Amoco's Stacey Contends," *The Oil Daily*, Apr. 25, 1988, p. 9.

[4] *Ibid.*

[5] Industry contacts.

[6] *Annual Energy Review*, 1990 (Department of Energy, May 1991), p. 7.

[7] *Ibid.*, p. 31.

[8] *Ibid.*, p. 19.

[9] *Ibid.*, p. 114.

[10] *Ibid.*, p. 110.

[11] "Study Shows Good Oil Wells in Steep Decline, Nugent Says," *The Oil Daily*, Feb. 2, 1988, pp. 1, 3.

[12] Bruce A. Pasternack, "Change, Uncertainty Mark U.S. Natural Gas Market," *The Oil and Gas Journal*, vol. 86, no. 23, June 6, 1988, pp. 42–45.

[13] *Natural Gas Production Responses to a Changing Market Environment, 1978–1988*, Energy Information Administration, May 1990, p. 53.

[14] Industry contacts.

[15] *Competition in the Petroleum Industry*, submission of Exxon Company, U.S.A., before the Senate Judiciary Subcommittee on Antitrust and Monopoly, Jan. 21, 1975, p. 11.

[16] Industry contacts.

[17] Statistics from the American Association of Petroleum Geologists and the American Petroleum Institute; see *Basic Petroleum Data Book*, American Petroleum Institute, May 1990, Section III, tables 1,2.

[18] American Petroleum Institute data, *Basic Petroleum Data Book*, section II, table 3.

[19] Statistics from the American Association of Petroleum Geologists and the American Petroleum Institute.

[20] Industry contacts.

[21] Based on data published by *World Oil* magazine and appearing in *Basic Petroleum Data Book*, section III, table 19.

[22] *Annual Energy Review*, 1990, Department of Energy, May 1991, p. 171.

[23] *Natural Gas Production Responses*, p. IX. Gas fields could have produced at higher levels than they did. This was demonstrated in 1984, when average production per well increased in response to a short-term increase in demand.

[24] Annual National Stripper Well Survey, various years.

[25] *Natural Gas Production Responses*, p. X.

[26] Figures based on data from Census of Mineral Industries.

[27] *Ibid.*

[28] Salomon Bros., Inc., *Proved Petroleum Reserves of 30 Large Energy Companies, 1981–88*, 1989 edition. (Taken from *Basic Petroleum Data Book*, section V, table 11.)

[29] American Petroleum Institute data; see *Basic Petroleum Data Book*, May 1990, section V, table 11.

[30] Industry contacts.

[31] "Oil: Basic Analysis," *Standard and Poor's Industry Survey*, vol. 157, no. 31, sec. 1, Aug. 3, 1989, p. O–44.

[32] Based on data from Census of Mineral Industries.

[33] *Competition in the Petroleum Industry*, p. 6.

[34] "What's New in Artificial Lift," *World Oil*, May 1989, pp. 30–39. A sucker rod pump is a deep oil well pump fixed at the foot of the well. It consists of a working barrel and hollow plunger operated by a line of rods hung from a walking beam at the surface. Shutoff systems are devices by means of which the flow of gas or oil can be made to cease.

[35] *Competition in the Petroleum Industry*, p. 13.

[36] "Oil: Basic Analysis," p. O–44.

[37] *Competition in the Petroleum Industry*, pp. 12–13.

[38] Sharon Denny, "Computers Become Standard Equipment in the Oil Industry," *The Oil Daily*, Nov. 11, 1983, p. B3.

[39] *Competition in the Petroleum Industry*, p. 13.

[40] Reuven Hollo, "Integrated Software Speeds Improved Reserve Evaluation," *The Oil and Gas Journal*, vol. 86, no. 37, Sept. 12, 1988, pp. 94–95.

[41] See "PLC's Used for Offshore Production Platform Control," *The Oil and Gas Journal*, vol. 86, no. 29, July 18, 1988, pp. 38–43; and Richard A. Kowalski, "PLC's are Now Preferred in Many Oil Field Operations," *The Oil and Gas Journal*, vol. 86, no. 25, June 20, 1988, pp. 59–62.

[42] "Researchers Study Reservoir Cyclic Depletion Process," excerpt from *Advanced Recovery Week*, sample issue, 1989, p. 2.

[43] "Amoco CO_2 Project Hikes Wasson Oil Recovery," *The Oil and Gas Journal*, vol. 85, no. 43, Oct. 26, 1987, p. 24.

[44] Weeden, "Miscible Flood EOR," p. 9.

[45] *Annual Outlook for Oil and Gas, 1989*, Department of Energy, June 1989, p. 7.

[46] Data from Department of Energy.

[47] Industry contacts.

[48] Scott L. Weeden, "Advances in Enhanced Production Will Maximize Natural Gas Output," *The Oil Daily*, June 16, 1988.

[49] *Annual Outlook for Oil and Gas, 1989*, p. 7. Also, industry contacts.

[50] "Good Oil Wells in Steep Decline," pp. 1, 3.

[51] *Annual Outlook for Oil and Gas*, 1989, p. 10.

[52] "Oil: Basic Analysis," p. O–33.

[53] John Holusha, "They're Drilling in the Oil Patch Again," *The New York Times*, June 17, 1990, section 3, pp. 1, 6.

[54] "Oil: Basic Analysis," p. O–35.

[55] Rick Hagar, "Subsea Completions Bringing More Deepwater, Marginal Fields in Reach," *The Oil and Gas Journal*, vol. 86, no. 21, May 23, 1988.

[56] "Microbial Oil Recovery Test Starts in Oklahoma," *The Oil and Gas Journal*, vol. 85, no. 4, Jan. 26, 1987, p.

30. In this technique, living organisms are introduced into the underground oil. The metabolic processes of these organisms can change oil viscosity and add gas pressure to the reservoir.

[57] *Petroleum Industry Technology to Meet Today's Challenges*, discussion paper no. 067, June 1991, p. 19.

[58] "Oil: Basic Analysis," p. O–41.

APPENDIX: Measurement techniques and limitations

Indexes of output per employee hour measure changes in the relation between the output of an industry and 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.

The preferred output index of mining industries would be obtained from data on quantities of the various materials produced by the industry, each weighted (multiplied) by the employee hours required to produce one unit of each good in some specified base period. Thus, those products which require more labor time to produce are given more importance in the index.

The output index for this industry was developed from data on the quantities of crude oil and natural gas produced. Employee hour weights were developed to combine these two components into an output measure through 1972. When data to develop these weights were no longer available, price weights were developed to combine oil and gas produced from 1972 forward.

Employment and employee hour indexes were derived from data published by the Bureau of Labor Statistics. Employees and employee hours are each considered homogeneous and additive and thus do not reflect changes in the qualitative aspects of labor, such as skill and experience.

The indexes of output per employee hour do not measure any specific contributions, such as that of labor or capital. Rather, they reflect the joint effect of factors such as changes in technology, capital investment, capacity utilization, plant design and layout, skill and effort of the work force, managerial ability, and labor-management relations.

Erratum

In "Auto industry jobs in the 1980's: a decade of transition," by Christopher Singleton, *Monthly Labor Review*, February 1992, the legends in chart 3 (page 21) are transposed. The black bar represents sales of the "Big Three and American Motors" and the dark grey bar represents Japanese "Transplant sales."