Multifactor productivity advances in the tires and inner tubes industry

Upswings in both output per employee hour and multifactor productivity were aided by the rapid diffusion of radial tire-related technology and computer-assisted innovation in the manufacturing process

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Many factors influence movements in labor productivity, such as technological change, changes in the skills and efforts of the work force, economies of scale, and the amount of capital input per worker and intermediate purchases input per worker. For many years, the Bureau of Labor Statistics has published a labor productivity measure for the tires and inner tubes industry as measured by output per employee hour. This article presents a supplementary productivity measure for the tires and inner tubes industry—multifactor productivity—in which output is related to the combined inputs of labor, capital, and intermediate purchases. Multifactor productivity differs from the traditional measure in that it accounts for the influences of capital and intermediate purchases in the input measure and therefore does not reflect the impact of these influences in the productivity residual.

Output per employee hour in the tires and inner tubes industry experienced substantial growth during the 1958–86 period, averaging 3.2 percent per year, as output increased 2.4 percent, while hours dropped 0.8 percent per year. For the manufacturing sector as a whole, the average rate of increase in output per employee hour was 2.5 percent.

Output per employee hour can be described as the sum of the effects of changes in capital and intermediate purchases inputs relative to labor and changes in multifactor productivity. (See table 1.) The influence of capital on output per employee hour will be referred to as the "capital effect" and is measured as the change in the capital-labor ratio multiplied by the share of capital income in total output. Similarly, the influence of intermediate purchases on output per employee hour will be referred to as the "intermediate purchases effect" and is measured as the change in the intermediate purchases-labor ratio multiplied by the share of intermediate purchases in total output. Multifactor productivity growth accounted for 1.7 percentage points of the 3.2-percent gain in output per employee hour, while the intermediate purchases effect accounted for 1.1 percentage points and the capital effect for 0.4 percentage point over the 1958–86 period. The 1.7 percentage points growth in multifactor productivity (or output per unit of combined inputs) reflected a 2.4-percent growth in output, while combined inputs increased at an average rate of 0.7 percent.

Output per employee hour for this industry did not experience the post-1973 slowdown that was present for the manufacturing sector as a whole. Output per employee hour, which increased at a rapid 3.9-percent rate in the 1958–73 period, accelerated slightly to a 4.3-percent growth rate between 1973 and 1986. This acceleration in output per employee hour was accompanied by a dramatic falloff in the growth rate of output. Output, which had experienced a rapid 5.7-percent growth rate in the 1958–73 period, declined at a rate of 0.9 percent in the latter period. Hours, which rose slightly in the first period

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at a rate of 1.7 percent, fell dramatically in the second period, declining at an average annual rate of 5.0 percent.

Multifactor productivity accelerated more than labor productivity, from a 1.1-percent growth rate in the 1958–73 period to 3.6 percent in 1973–86. (See table 2.) The slight acceleration in output per employee hour occurred in spite of slowdowns in the growth rates of the capital effect and the intermediate purchases effect, because of this relatively rapid increase in multifactor productivity. The capital effect slowed from an average growth rate of 0.6 percent during 1958–73 to 0.1 percent in the following period. The growth rate of the intermediate purchases effect fell faster, averaging 2.1 percent in the 1958–73 period and 0.6 percent in the following years. (See chart 1.) Upswings in both output per employee hour and multifactor productivity were aided by the rapid diffusion of radial tire-related technology and computer-assisted innovations in the manufacturing process.

The capital effect (the weighted change in the capital-labor ratio) reflects the differential movements in its components. The slowdown in the capital effect can be decomposed into changes in capital services, labor, and the capital share weight. Capital services plunged from a 6.1-percent average annual gain in the first period to a 3.7-percent decline in the latter period. (See table 3.) The falloff in labor hours was less sharp—from a growth rate of 1.7 percent in the first period to a decline of 5.0 percent per year in the second period. The greater falloff in the growth rate of capital relative to that of labor resulted in a slowdown in the growth of the capital-labor ratio. The average annual growth rate in the capital-labor ratio fell from 4.4 percent during 1958–73 to 1.3 percent during 1973–86. Weighted with capital's share in the value of total output of 16 percent, this drop translated into a slowdown of 0.5 percent in the capital effect, from 0.6 to 0.1 percent.

Table 1. Average annual growth rates in output per employee hour, multifactor productivity, and related measures, tires and inner tubes industry, 1958–86

Measure	1958–86	1958–73	1973–86	Acceleration (+) or slowdown (–)
Output per employee hour[1]	3.2	3.9	4.3	+0.4
Multifactor productivity	1.7	1.1	3.6	+2.5
Capital effect[2]	.4	.6	.1	–.5
Intermediate purchases effect[3]	1.1	2.1	.6	–1.5

[1]Output per employee hour equals multifactor productivity plus the capital effect plus the intermediate purchases effect.

[2]The capital effect is the change in the capital-labor ratio multiplied by the share of capital income in total output.

[3]The intermediate purchases effect is the change in the intermediate purchases-labor ratio multiplied by the share of intermediate purchases income in total output.

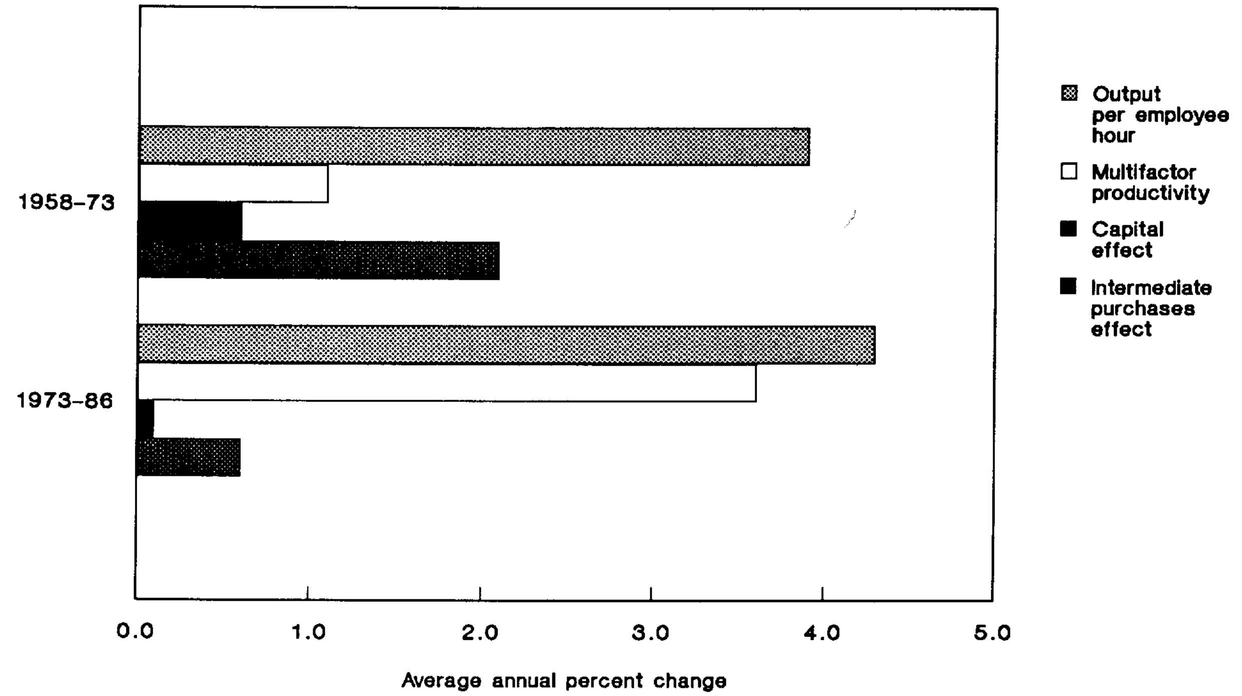
The intermediate purchases effect (the weighted change in the intermediate purchases-labor ratio) can be decomposed in a similar fashion, although its value share is much larger than that of capital, averaging 59 percent for the period. Intermediate purchases increased 5.2 percent annually during 1958–73, but declined 4.0 percent per year in the later period. Consequently, the growth in the intermediate purchases-labor ratio slowed from a 3.4 percent annual rate in the first period to 1.1 percent in the 1973–86 period. This falloff, weighted by the value share of intermediate purchases, resulted in a 1.5-percent slowdown in the intermediate purchases effect from 2.1 percent annually in the first period to 0.6 percent in the latter period.

Output

The output of this industry comprises tires, which accounted for 92 percent of the value of shipments in 1982; inner tubes, which accounted for 2 percent; and tread rubber, which accounted for 6 percent of the value of shipments. In the same year, passenger car tires accounted for 79 percent of all tires; truck and bus tires, for 15 percent; and aircraft, industrial, and bicycle tires constituted the remaining 6 percent. As mentioned earlier, output grew at the relatively high average annual rate of 5.7 percent in the period 1958–73, then fell off precipitously in the following period, declining at a rate of 0.9 percent. (See table 4.) Even during the high output growth period of 1958–73, the rate of increase slowed. During 1958–66, the average annual rate of growth was 6.6 percent, while in the 1966–73 period, it was 5.1 percent. In the post-1973 period, double-digit declines in 1974–75 (–13.5 percent) and 1979–80 (–21.9 percent) occurred mainly as a reaction to two major recessions. The recessions affected both the original and replacement tire markets. The original tire market was depressed due to declining auto sales, while the replacement market was affected by concurrent soaring gasoline prices which resulted in fewer miles driven. The average number of miles driven per car peaked at 11,500 in 1972. It again reached that number in 1978 before the energy crisis pushed average miles down to 11,000 in 1979 and down even further to 10,600 in 1980.[1]

Fluctuations in output are greatly influenced by changes in the passenger car replacement tire market, as passenger car tires account for about three-fourths of all tires[2] and replacement tires account for 73 percent of all passenger car tires sold.[3] One key factor for the declining output in the replacement tire market since the early 1970's is the greater longevity of car tires brought about by the introduction of radials. In the past two decades, this has been responsible for the doubling of tire service life.[4] Additionally, studies have shown that although front tires are wearing faster than rear tires on the growing share of front-wheel drive cars, the average mileage on all four

Chart 1. Output per employee hour in the tires and inner tubes industry accelerated slightly after 1973, despite falloffs in capital and intermediate purchases relative to labor, as multifactor productivity surged



tires is one-fourth to one-third greater than the average mileage obtained from four tires on a comparable rear-wheel drive car.[5] Also, as noted, relatively high gasoline prices negatively affect miles driven and, thus, have a negative impact on the replacement tire market. As mentioned before, average driver miles per year peaked in 1972, reaching 11,500, decreased during the two energy crises, but is once again rising.[6]

The decrease in domestic car production over the period studied has severely affected the original tire market. Auto production declined 18 percent between 1973 and 1974 and fell 19 percent between 1974 and 1975. Although production rebounded in the 1976–78 period, output fell 26 percent in the 1979–80 period and production levels have remained below 1979 levels through 1986.[7] Domestic tiremakers face not only contraction in the domestic tire market, but also a growing import share. Tires from France, Japan, South Korea, and other nations accounted for 23.7 percent of the U.S. replacement tire market in 1987, compared with 10.8 percent in 1980.

Capital

Capital input is the flow of services derived from the equipment needed in the production of tires and tubes, structures (mostly buildings which house the production process), finished goods, work-in-process, and materials and supplies inventories that are kept on hand in the firm, and the land on which plants are located. For the 1958–86 period, capital input in the tire industry rose an average 2.1 percent per year. From 1958 to 1973, capital input increased at a rapid rate of 6.1 percent per year, exceeding the average annual increase in output of 5.7 percent. During the post-1973 period, however, capital input fell by 3.7 percent per year, considerably more than the output decline for that period (–0.9 percent).

Capital input rose steadily beginning in 1958 and at a faster rate than output, reaching its peak in 1975—approximately 150 percent above the earlier year. Many new plants which were built in the late 1960's and early 1970's were designed specifically for radial tire production. Approximately nine new plants began operation in the 1968–75 period.[8] Also, some plants were being converted from bias-belted to radial tires, requiring additional equipment and workers. The extra equipment reduces the number of work stations a given plant can hold. Thus, a plant that has been converted to radials produces fewer tires for any given investment.[9]

From 1976 to 1986, capital input decreased in every year, except for a slight gain in 1985, so that its level in that year was approximately the same as in 1967, about 35

Table 2. Multifactor and related productivity indexes in the tires and inner tubes industry, 1958–86
[1977 = 100]

Year	Multifactor productivity	Output per employee hour	Output per unit of capital	Output per unit of intermediate purchases
1958	73.9	52.7	87.7	80.5
1959	79.7	58.2	103.5	84.2
1960	80.2	59.7	95.5	85.9
1961	81.1	61.7	87.5	88.2
1962	84.9	67.9	95.5	89.6
1963	87.7	72.9	97.1	91.6
1964	92.8	79.4	104.2	95.6
1965	92.1	80.9	103.5	93.9
1966	90.8	82.4	104.4	90.9
1967	86.3	82.2	90.8	86.6
1968	91.0	87.8	100.9	89.7
1969	87.4	85.1	91.6	87.0
1970	86.4	87.2	80.4	87.6
1971	91.7	93.5	87.9	91.6
1972	93.5	97.1	94.0	91.2
1973	92.7	94.3	90.4	92.2
1974	90.8	92.2	86.8	91.0
1975	87.3	90.8	73.0	89.9
1976	90.9	99.4	77.4	91.3
1977	100.0	100.0	100.0	100.0
1978	103.6	108.1	99.5	102.7
1979	105.5	107.6	99.2	106.1
1980	103.4	102.2	80.5	110.0
1981	112.1	118.1	91.3	114.8
1982	118.9	128.8	93.0	121.9
1983	126.9	136.6	107.2	126.6
1984	132.6	147.7	128.2	124.2
1985	130.9	147.3	120.5	124.0
1986	134.5	151.2	116.5	130.2
	Average annual rates of change (percent)			
1958–86	1.7	3.2	0.4	1.4
1958–73	1.1	3.9	−0.4	0.5
1973–86	3.6	4.3	3.0	3.2

percent below its peak. The decline of capital input after 1975 occurred because the conversion of tire plants from bias to radial production was completed. By 1976, conversion to radial capacity had reached its final stages for most producers, so that capacity was ample and there was less need for purchases of new processing equipment.

Movements in the stocks of the various types of capital input—equipment, structures, inventories, and land—were not always the same. For the earlier period, in which capital input grew by a significant 6.1-percent average annual rate, the growth rate for equipment was 6.7 percent, and for structures, 7.1 percent. Land input also grew faster than capital input—at a 7.1-percent average annual rate. However, inventories grew at a slower 4.8 percent rate.

During the later period, 1973–86, when capital input fell by 3.7 percent per year, equipment steadily declined by an average annual rate of 5.0 percent. Inventories also dropped off significantly after 1975, resulting in an average annual decrease of 6.8 percent during the 1973–86 period. However, increases in the stocks of structures continued between 1973 and 1980 before finally declining after 1980. Land requirements increased an average 0.9 percent in the post-1973 period, and, as in the case of structures, continued to rise during 1973–81, and then fell off in later years.

Inventories of finished goods and raw materials were built up in the mid-1970's in anticipation of strikes by members of the United Rubber Workers union. The manufacturers were able to stockpile up to 90 days of inventory. However, in the late seventies and early eighties, inventories fell much faster than output. The drop in inventories in the late 1970's can be attributed to the decrease in the demand for tires.

Labor

Employee hours declined at an average annual rate of 0.8 percent over the 1958–86 period. Between 1958 and 1973, when output grew at a rapid rate of 5.7 percent, employee hours increased at a rate of 1.7 percent. However, while output decreased at a rate of 0.9 percent in the 1973–1986 period, employee hours declined 5.0 percent per year. Trends in employment were similar to those in total employee hours, as average weekly hours, although fluctuating somewhat from year to year, showed no long-term growth or decline.

In 1982, establishments in the tire industry averaged 429 employees, compared with 727 employees in 1958. This decrease resulted from reductions in labor requirements, and occurred despite increases in the number of tires produced per establishment. The average number of employees per plant has been much greater in the tire industry than in total manufacturing. The average for all manufacturing industries increased from 53 employees per plant in 1958 to a high of 62 in 1967, but has decreased since then to its 1958 level. The average for the entire industry (Standard Industrial Classification 3011) is lowered by the inclusion of smaller plants producing products other than tires. Plants with 500 or more employees, which would include virtually all tire plants, employed an average of 1,471 workers in 1982. Eighty percent of total employment in 1982 for the tires and inner tubes industry was in establishments with 1,000 employees or more.

Many changes that have directly affected employment have taken place in the latter period. In 1974, employment peaked at 117,300. This occurred concurrently with rising demand and the retooling of plants for the production of radial tires. In the interval 1974–76, employment declined steeply. Factors responsible for this decline were decreased auto sales and, thus, reductions in original tire sales; a decline in miles driven attributable to the energy crunch; and low replacement tire sales as the popularity of radials increased. In addition, a lengthy United Rubber Workers strike in 1976, from mid-April to the end of August, kept average employment levels low in that year.

In 1977, employment rebounded after the strike, spurred by a strong output gain, only to decrease steadily thereafter until 1984. This decline was chiefly as a result of 24 plant closings since 1978; only five plants began operations during this period. The closed plants were mainly bias and bias-belted tire operations that were made obsolete by the conversion to radial tires. Also slowing tire demand in the early 1980's were the continued popularity of the longer-lived radial and increased penetration of foreign sales into the domestic market.

Intermediate purchases

Intermediate purchases grew at a 1.0-percent average annual rate for the period 1958–86. This figure reflects a fairly rapid growth rate of 5.2 percent in the earlier period 1958–73, while intermediate purchases declined by 4.0 percent per year in the latter period—a falloff of 9.2 percent. Intermediate purchases productivity accelerated from one period to the other—rising from a 0.5-percent annual average rate of growth in the 1958–73 period to a 3.2-percent rate for the second period. Intermediate purchases fell off more sharply than output between the two intervals, partly attributable to technological changes aimed at reducing materials wastage and to the production of smaller diameter tires for smaller cars.

Intermediate purchases are composed of materials, fuels, electricity, and purchased services. Of these components, materials is by far the largest, constituting 84 percent of intermediate purchases on average. In 1982, the latest year for which detailed data are available, styrene-butadiene (SBR, a synthetic rubber) made up 29 percent of total materials consumed in census-specified items. Tire cord (nylon and polyester) constituted 24 percent; carbon black, 19 percent; natural rubber, 18 percent; and rubber processing chemicals, 11 percent.

Since 1958, synthetic rubber has become an increasing percentage of total rubber consumed by the tires and inner tubes industry, in spite of the fact that radials contain twice the amount of natural rubber as bias tires. While natural rubber steadily decreased from 23 percent of total census-specified items in 1958 to 12 percent in 1982 (the latest available year), synthetic rubber decreased only slightly from 32 percent in 1958 to 31 percent in 1982. However, as the conversion to radials continues, it is expected that consumption of natural rubber for tires will increase. Counter to this trend are the projected increase in the popularity of retreading, the downsizing of tires, and the increased use of polyisoprene. In many tire applications, synthetic polyisoprene may be substituted for natural rubber. This elastomer has the advantage of uniformity, automated processing, and production near the consuming industry. Partly because of the inroads of synthetic polymers into natural rubber demand, synthetic polymers will continue to be the major elastomer used in passenger tire production. In 1984, world consumption of polyisoprene was 20 percent of natural rubber. Currently, radial passenger tires contain about 30 percent synthetic rubber, while the percentage for natural rubber is slightly less.[10]

Table 3. Average annual rates of growth in output per employee hour and related measures in the tires and inner tubes industry, 1958–86

Measure	1958–73	1973–86	Acceleration (+) or slowdown (–)
Output per employee hour	3.9	4.3	+0.4
Employee hours	1.7	–5.0	–6.7
Capital	6.1	–3.7	–9.8
Capital per employee hour	4.4	1.3	–3.1
Capital effect[1]	.6	.1	–.5
Intermediate purchases	5.2	–4.0	–9.2
Intermediate purchases per employee hour	3.4	1.1	–2.3
Intermediate purchases effect[2]	2.1	.6	–1.5

[1]Capital per employee hour multiplied by the share of capital income in total output.

[2]Intermediate purchases per employee hour multiplied by the share of intermediate purchases income in total output.

Except for natural rubber, the raw materials mentioned earlier are largely composed of petroleum derivatives. As such, they are subject to price fluctuations in response to oil price changes. The average annual increase of 10 percent in the price of materials for the years 1973–82 is chiefly attributable to the rapid increase in the cost of petroleum derivative materials. This rapid increase was attributable to the tremendous oil price hikes of 1973–75 and 1980–82. Fueling this 10-percent average price rise were four double-digit rises. These price pressures from the oil sector were the main cause of jumps of 22 percent between 1973 and 1974 and 17 percent from 1979–80 in the overall price of tire materials. The average annual rate of growth for the 1958–72 period had been –0.2 percent.

Technological innovations have been introduced during the 1973–86 period to avoid materials wastage. In the calendering process, the reduction of waste is critical because fabric is relatively expensive and scrap produced is impossible to rework. The industrywide adaptation of computer monitoring of the calendering step assures uniformity of calendered fabric, reduces scrap, and prevents excessively thick sections of calendered stock. Computer monitoring in the tire curing process also minimizes waste. Because unsatisfactory conditions are immediately detected by the computer, at most only one round of tires can be improperly cured.

Another explanation of the slow growth in intermediate purchases relative to output growth that has been offered is that, during the 1973–86 period, lighter and more sophisticated tire construction, attributable to the downsizing of the American automobile, predominated. In terms of rubber consumption, 30 percent less rubber is used in tires which average 13 inches versus the previous 14- to 15-inch standard and are 10 to 15 pounds lighter

Table 4. Output and input indexes in the tires and inner tubes industry, 1958–86
[1977 = 100]

Year	Output	Combined inputs	Employee hours	Capital	Intermediate purchases
1958	39.9	54.0	75.7	45.5	49.6
1959	47.5	59.6	81.6	45.9	56.4
1960	47.1	58.7	79.0	49.3	54.8
1961	45.7	56.4	74.1	52.2	51.8
1962	52.1	61.4	76.7	54.5	58.1
1963	54.2	61.7	74.3	55.8	59.1
1964	61.0	65.8	76.9	58.6	63.8
1965	64.6	70.1	79.9	62.4	68.8
1966	69.2	76.2	84.0	66.3	76.2
1967	64.3	74.5	78.2	70.8	74.3
1968	78.1	85.9	88.9	77.4	87.1
1969	79.9	91.5	94.0	87.2	91.9
1970	75.7	87.6	86.9	94.2	86.5
1971	84.9	92.6	90.8	96.6	92.8
1972	92.8	99.2	95.6	98.7	101.8
1973	93.6	100.9	99.2	103.5	101.4
1974	94.8	104.4	102.8	109.2	104.1
1975	82.0	93.9	90.2	112.2	91.2
1976	81.4	89.6	81.9	105.2	89.1
1977	100.0	100.0	100.0	100.0	100.0
1978	97.2	93.8	89.8	97.6	94.6
1979	94.1	89.2	87.4	94.9	88.7
1980	73.5	71.1	71.9	91.3	66.9
1981	79.0	70.5	66.9	86.5	68.9
1982	75.0	63.0	58.2	80.6	61.5
1983	79.8	62.9	58.4	74.4	63.0
1984	91.3	68.9	61.9	71.2	73.6
1985	86.8	66.3	58.9	72.0	70.0
1986	83.6	62.2	55.3	71.7	64.2
	Average annual rates of change (percent)				
1958–86	2.4	0.7	-0.8	2.1	1.0
1958–73	5.7	4.5	1.7	6.1	5.2
1973–86	-0.9	-4.3	-5.0	-3.7	-4.0

than the former 30-pound average. One industry official cites a 50-percent decline in total North American styrene-butadiene rubber consumption since 1979.[11]

Technological change

In the period studied, many innovations were introduced to achieve the current state-of-the-art in tire production. In the 1950's, tubeless tires were introduced along with the first successful commercial preparation of synthetic rubber. The 1960's saw the advent of the first commercial use of polyester tire cord; but the most critical development was the first commercial production in the United States of the radial tire in 1965. The introduction of radials prompted significant changes to many steps in the production process. In the two decades that followed, computer technology was applied to almost every aspect of production.[12]

The introduction of the radial has helped induce the closing of old and inefficient plants embedded with technology designed for bias and bias-belted tires. Radial technology required equipment and process changes that older plants could not accommodate; therefore, new plants incorporating the new technology had to be built and the old plants shut down. Twenty-seven tire plants have been shut down since 1975. However, 26 new tire plants have been built since 1960, 15 of them since 1969. The new plants have increasingly included automated equipment and more efficient material handling machinery. Plants were also built in decentralized areas where the cost of shipping raw materials was less, and land was less expensive. All of these changes have added up to decreased costs of production, as compared with the older tire plants.[13]

With automation and the complications of radial tire production, plant designs have been improved to allow for a continuous flow of materials from the beginning of the manufacturing process to the end. Computer monitors are now being used to schedule the wide variety of styles and sizes to ensure that all capital equipment is being fully utilized. Each stage of the tire building process—raw materials handling, mixing, calendering, extrusion, tire-building, curing—has been made more efficient by the use of innovations. Increasingly, raw materials are received in bulk load quantities and stored in bulk storage bins rather than in bags or drums. Automated systems that weigh and feed materials directly into mixers reduce the number of workers needed to handle raw materials and reduce error in the measurement of different materials used in production of the various types of tires.[14]

Mixing is one of the most capital-intensive procedures of the production process. In the 1960's, the newly developed high powered motors of the Banbury mixer allowed mixing times to be reduced by 90 percent and high-speed mixes to be completed in 2 minutes.[15] Consequently, an extruder was developed to handle this higher rate of output. Uncured treads and sidewalls are processed in extruders in what has become a very capital-intensive operation. Previously, tire strips had to be cut by hand in predetermined lengths to wrap exactly around the "green" carcass. If the strip was not exact, a non-uniform tire resulted. However, a process has been developed called "orbitread," which enables the winding of the tread strip onto the "green" tire. The benefits of such a process include: requirement of a much smaller extruder (therefore, less initial capital investment), elimination of tread splices, better adhesion through application of hot treads to the "green" tire, and improved uniformity.[16]

Calendering, the process in which the tire fabric is impregnated with the extruded rubber stock, is also capital intensive. Normally, a calender's maximum size is so large that it can never be fully utilized. The most important innovation in this process was the adaptation of computer controls, as early as 1974, which ensure uniformity, reduce scrap, and prevent excessively thick stock. Waste is critical as the fabric is expensive and the scrap cannot be reworked. This factor becomes increasingly important with increases in the price of raw materials. Both the elimination of waste and the increase in line speed reduce operating costs and increase production. Previously, a calender operator cut and measured the stock sheet manually and the calender was adjusted by trial and error.[17] Fabric preparation for the calendering process, especially for steel belting, has required newly designed or modified equipment in order to account for differences in roll widths, weights, take away equipment, and cutting.

Tire building is the most labor-intensive step in the production process. Attempts to automate this process have been made in order to decrease labor costs and increase tire uniformity. The conventional method of building bias-belted tires is to manually apply the tire components onto a rotating drum. Automation is hampered by the large variety of tire styles and types. Radial tires further complicate automation by requiring two separate building stages and the need to shape the tire while building.[18]

Automation in the final production step, tire curing, has decreased production time. Early in the 1960's, tires were moved by conveyors to the tire presses. The tire curing press was totally automated except for an operator inserting the "green" tire into the press and then transferring the cured tire to the finishing area. Typically, 17 workers were needed to complete this process, but by the mid-1960's, only two were needed.[19] At one of the major tire companies, a computer monitoring system has been installed which performs 22 checks to detect any deviations from established standards. Curing, temperature range, and process time are optimized in this way.[20] Another important objective of the computerized tire-curing process is to eliminate waste by reducing the number of defective tires.[21] Segmented molds were needed for radial tires in the curing process and added to the cost of investment, but were not a difficulty in conversion.[22] Previously, one-half of the mold was closed upon the other, forcing the tread design onto the uncured tire. Segmented molds (of six to eight parts) prevent distortion of the uncured tire as the mold is closed upon it; they also prevent the damage to the cured tire that occurs when the relatively inflexible radial is taken out of a regular mold.[23]

Tire finishing, warehousing, and shipping have also been made less labor intensive through automated tire-movers and inspection stations. By the early 1980's, even tire design had been transformed by the adoption of computer-assisted drafting, which reduces repetitive handwork. It has been estimated that it takes 2.5 days to design a tire mold for a new tire style, whereas before it took 21 days. Once the design is drafted, 12 to 15 different tire molds can easily be produced by using a computer.[24]

Summary

Output per employee hour in the tires and inner tubes industry grew at an average annual rate of 3.2 percent over the 1958–86 period. Multifactor productivity growth accounted for 1.7 percentage points of this gain, while the intermediate purchases effect accounted for 1.1 percentage points, and the capital effect, 0.4 percentage point. The growth of multifactor productivity was substantially higher in the post-1973 period, accounting for 3.6 percentage points of the 4.3-percent average annual growth rate in output per employee hour for the same period.

The growth of output per employee hour did not slow down after 1973 as it did in many industries and was well above the manufacturing average of both the pre- and post-1973 periods. While output itself grew at a rapid 5.7-percent rate in the first period, its growth rate dropped dramatically in the latter period. This decrease in production reflects the greater longevity of radial tires, decreases in domestic car production, and increasing penetration of foreign firms into the U.S. replacement tire market.

The production of radial tires has introduced many changes to the production process. Automation and computer technology have also been applied to many stages of production, decreasing costs and increasing productivity. □

———*FOOTNOTES*———

1 Newslog, "Study Predicts Tire Needs Will Drop," *Elastomerics*, August 1982, p. 36.

2 Data are for 1984 and are from the Rubber Manufacturers Association.

3 "Tire Imports Pressure U.S. Makers," *The Washington Post*, Mar. 1, 1987, Sec. H, p. 1. Data are for 1984.

4 J. S. Dick, "How Technological Innovations Have Affected the Tire Industry's Structure: Part VI," *Elastomerics*, February 1981, pp. 42–47.

5 "Study Predicts Tire Needs Will Drop," *Elastomerics*, August 1982, p. 36.

6 *Ibid.*

7 *Ward's Automotive Yearbook* (Detroit, Ward's Communications, Inc., various years).

8 J. S. Dick, "How Technological Innovations Have Affected the Tire Industry's Structure: Part II," *Elastomerics*, October 1980, p. 36.

9 D. H. Blank, "Tire Industry Study" (International Trade Administration, U.S. Department of Commerce, March 1979), pp. 17–18.

10 Frank W. Stuchal, "Tire Material Trends into the Nineties," *Elastomerics*, January 1984, p. 15.

11 "Rubber Firms Seek Efficiency," *Chemical Marketing Reporter*, Aug. 25, 1986, p. 3.

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APPENDIX: Multifactor productivity measurement

Methodology and data definitions

The following is a brief summary of the methods and data underlying the multifactor productivity measure for the tires and inner tubes industry. A technical note, describing the procedures and data in more detail, is available from the Office of Productivity and Technology, Bureau of Labor Statistics, Washington, DC 20212.

Output. The output measure for the tires and inner tubes industry is based on the weighted change in quantity of production of various types of tires and inner tubes as reported by the Rubber Manufacturers Association. This measure is, in turn, benchmarked to indexes of constant dollar production calculated from detailed quantity and value data published in the *Census of Manufacturers* for 1958, 1963, 1967, 1972, 1977, and 1982.

For multifactor measures of individual industries, output is defined as total production, rather than the alternative of value added. For a value-added measure, intermediate inputs are subtracted from total production. Consequently, an important difference between the industry level measures and the multifactor productivity indexes that BLS publishes for aggregate sectors of the economy is that the major sector measures are constructed within a value-added framework. For the major sectors of the economy, intermediate transactions tend to cancel out. Intermediate inputs are much more important in production at the industry level.

Further, output in these measures is defined as total production which "leaves" an industry in a given year in the form of shipments plus net changes in inventories of finished goods and work in process. Shipments to other establishments within the same industry are excluded, when data permit, because they represent double counting which distorts the productivity measures.

Labor. Employee hour indexes, which represent the labor input, measure the aggregate number of employee hours. These hours are the sum of production worker hours from *Censuses* and *Annual Surveys of Manufactures* and nonproduction worker hours derived by multiplying the number of nonproduction workers from Census by an estimate of nonproduction worker average annual hours. The labor input data are the same as those used in the published BLS output per employee hour series.

Capital. A broad definition of capital input, including aequipment, structures, land, and inventories, is used to measure the flow of services derived from the stock of physical assets. Financial assets are not included.

For productivity measurement, the appropriate concept of capital is "productive" capital stock, which represents the stock used to produce the capital services employed in current production. To measure the productive stock, it is necessary to take into account the loss of efficiency of each type of asset as it ages. That is, assets of different vintages have to be aggregated. For the measures in this article, a concave form of the age/efficiency pattern (slower declining efficiency during earlier years) is chosen.

In combining the various types of capital stock, the weights applied are implicit rental prices of each type of asset. They reflect the implicit rate of return to capital, the rate of depreciation, capital gains, and taxes. (For an extensive discussion of capital measurement, see *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, 1983).)

Intermediate purchases. Intermediate purchases primarily include materials, fuels, electricity, and purchased business services. Materials measured in real terms refer to items consumed or put into production during the year. Freight charges and other direct charges incurred by the establishment in acquiring these materials are also included. The data from which the intermediate inputs are derived include all purchased materials and fuels regardless of whether they were purchased by the individual establishment from other companies, transferred to it from other establishments of the same company, or withdrawn from inventory during the year. An estimate of intra-industry transactions is removed from materials and fuels.

Annual estimates of the cost of services purchased from other business firms are also required for multifactor productivity measurement in a total output framework. Some examples of services are legal services, communications services and repair of machinery. An estimate of the constant dollar cost of these services is included in the intermediate purchases input.

Capital, labor, and intermediate purchases income shares. Weights are needed to combine the indexes of the major inputs into a combined input measure. The weights for this industry are derived in two steps. First, an estimate of income in current dollars for each input is derived. Second, the income of an input is divided by the total income of all inputs.

Conceptual framework

The multifactor productivity measure presented here is computed by dividing an index of output by an index of combined inputs of capital, labor, and intermediate purchases. The framework for measurement is a production function describing the relation of output and inputs and an index formula that is consistent with this production function.

The general form of the production function underlying the multifactor productivity measures is postulated as:

$$(1) \qquad Q(t) = Q\Big(K(t), L(t), M(t), t\Big),$$

where $Q(t)$ is total output, $K(t)$ is input of capital services, $L(t)$ is input of labor services, $M(t)$ is input of intermediate purchases, and t is time.

Differentiating equation *(1)* with respect to time, and with some algebraic manipulations, the sources-of-growth equation is:

$$(2) \qquad \frac{\dot{Q}}{Q} = A + w_k \frac{\dot{K}}{K} + w_l \frac{\dot{L}}{L} + w_m \frac{\dot{M}}{M},$$

where A is the rate of change of multifactor productivity, w_k is output elasticity (percentage change in output due to a 1-percent change in input) with respect to the capital input, w_l is output elasticity with respect to the labor input, and w_m is output elasticity with respect to the intermediate purchases input (the dot over a variable indicates the derivative of the variable with respect to time).

Equation *(2)* shows the rate of change of output as the sum of the rate of change of multifactor productivity and a weighted average of rates of change of capital, labor, and intermediate purchases inputs. Now, if competitive input markets are assumed, then each input is paid the value of its marginal product. The output elasticities in equation *(2)* can then be replaced by factor income shares:

$$w_k = \frac{P_k K}{P_q Q}, \quad w_l = \frac{P_l L}{P_q Q}, \quad \text{and } w_m = \frac{P_m M}{P_q Q},$$

where P_q is the price of output, and P_k, P_l, and P_m are the prices paid for the capital, labor, and intermediate purchases inputs, respectively. Furthermore, if constant returns to scale are assumed, then $w_k + w_l + w_m = 1$.

Equation *(2)* can be rewritten as:

$$(3) \qquad A = \frac{\dot{Q}}{Q} - w_k \frac{\dot{K}}{K} - w_l \frac{\dot{L}}{L} - w_m \frac{\dot{M}}{M}$$

In this expression, the growth of multifactor productivity can be seen as a measure of economic progress: it measures the increase in output over and above the gain due to increases in inputs.

Equation *(2)* can also be transformed into the contribution equation which allows for an analysis of the change in output per employee hour. First, subtract $\dot{L}/L$ from both sides of equation *(2)*. Because the weights sum to unity, apply the term $(w_k + w_l + w_m)$ to the $\dot{L}/L$ term inserted on the right-hand side. Next, gather terms with the same weight and derive the following equation:

$$(4) \qquad \frac{\dot{Q}}{Q} - \frac{\dot{L}}{L} = w_k\left(\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right) + w_m\left(\frac{\dot{M}}{M} - \frac{\dot{L}}{L}\right) + A$$

The left side of equation *(4)* is the growth rate of output per employee hour. The terms in parentheses on the right side are, in order, the rates of change in the capital–labor ratio and the intermediate purchases–labor ratio. Thus, the rate of growth in output per employee hour can be decomposed into the weighted sum of changes in these ratios plus the change in multifactor productivity.

Equations (*2*), (*3*), and (*4*) are Divisia indexes which require continuous data for computation. The BLS multifactor indexes are actually constructed according to a Tornquist formula which represents a discrete approximation to the Divisia index. The rate of change in output or an input is calculated as the difference from one period to the next in the natural logarithms of the variables. For example, $\dot{Q}/Q$ is calculated as $ln\ Q(t) - ln\ Q(t-1)$. Indexes are then constructed from the antilogarithms of this differential. The weights w_k, w_l, and w_m are calculated as the arithmetic averages of the respective shares in time periods t and $t-1$.