Multifactor productivity: cotton and synthetic broadwoven fabrics

Multifactor productivity in the industry rose during the 1972–91 period; major influences on industry performance include technological advances and international competition

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Multifactor productivity, an indicator of economic performance that relates output to the combined inputs of labor, capital, and intermediate purchases, rose by an average 0.8 percent per year between 1972 and 1991 in the cotton and synthetic broadwoven fabrics industry. Growth in multifactor productivity can result from numerous influences such as technological change, economies of scale, changes in the skills of the work force, and changes in the organization of production. In the broadwoven fabrics industry, technological change was perhaps the most important factor underlying multifactor productivity growth in the period, as there was widespread adoption of technological advances, such as modern weaving machines.

Another measure of productivity, output per employee hour, grew at an average annual rate of 3.1 percent during the 1972–91 period. The growth rate of this labor productivity measure exceeded that of multifactor productivity because of the substitution of capital—equipment, buildings, land, and inventories—and of intermediate purchases—materials, fuel, electricity, and purchased services—for hours of labor in the production process. The capital-labor ratio and the ratio of intermediate purchases to labor both increased substantially in the cotton and synthetic broadwoven fabrics industry during this period.

Although the Bureau of Labor Statistics has published industry labor productivity measures for decades, its first multifactor productivity measures for detailed industries were introduced relatively recently, in 1987. The new measure of multifactor productivity in the cotton and synthetic broadwoven fabrics industry presented in this article joins the previously published multifactor productivity measures for the following detailed industries: motor vehicles, steel, footwear, tires and tubes, farm and garden machinery, railroad transportation, household furniture, and metal stampings.[1]

Multifactor productivity

Multifactor productivity is equal to the ratio of output to combined inputs of labor, capital, and intermediate purchases. In the cotton and synthetic broadwoven fabrics industry, output fell by 0.2 percent per year on average between 1972 and 1991, while combined inputs fell even faster, at an average rate of 1.0 percent; as a result, multifactor productivity grew at an average annual rate of 0.8 percent. In the early years of this study, 1972–79, multifactor productivity growth averaged 1.1 percent per year and was somewhat higher than in the later years, 1979–91, when the average was 0.7 percent.

In each of the periods studied, labor productivity—calculated as output per employee hour—advanced more rapidly than multifactor

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productivity in the broadwoven fabrics industry. (See table 1.) This is due to the capital and intermediate purchases effects, which were positive in each of the periods; labor productivity growth is the sum of multifactor productivity growth, the capital effect and the intermediate purchases effect. Each effect is measured as the weighted change in the ratio of the nonlabor input to labor input, in which the weight is the nonlabor input's share in output. Between 1972 and 1991, the intermediate purchases effect, which equaled 1.9 percent per year on average, accounted for more than half of the growth of output per employee hour, which was 3.1 percent per year, and the capital effect, which equaled 0.4 percent per year, accounted for much less.

Labor productivity growth rose from an average annual rate of 2.5 percent in the 1972–79 period to 3.5 percent in the 1979–91 period, in contrast to the fall in multifactor productivity growth between those time periods. Output per employee hour accelerated in broadwoven fabrics in spite of the slowdown in multifactor productivity because both the capital effect and the intermediate purchases effect were higher in 1979–91 than in 1972–79. The capital effect climbed from a yearly average of 0.3 percent in the first period to 0.5 percent per year in the second period, while the intermediate purchases effect jumped from 1.2 percent to 2.3 percent.

The capital effect was higher in 1979–91 than in the previous period, despite a decline in the growth rate of capital, because the growth rate of labor shrank even more. While the growth rate of capital decreased from an average of 0.7 percent in 1972–79 to –0.5 percent in 1979–91, the growth rate of labor plummeted from a yearly average of –1.1 percent to –4.6 percent. Together, these changes produced a surge in the rate of growth of the capital-labor ratio, from an average annual rate of 1.7 percent to 4.3 percent. This rise drove the increase in the capital effect, because the other component of the effect, capital's share of output, dropped slightly, from an average of 15 percent in the initial period to an average of 14 percent in the latter period.

The intermediate purchases effect was also larger during the 1979–91 period, despite the fall in the average annual rate of growth of intermediate purchases, from 0.8 percent in the earlier period to –0.9 percent in the later period. The increase in the intermediate purchases effect occurred primarily because of the dramatic drop in the labor growth rate, which also fueled the escalation of the capital effect. Taken together, the changes in the growth rates of intermediate purchases and labor resulted in a substantial increase in the growth of the intermediate purchases-labor ratio, from a 1.9-percent average annual gain in 1972–79 to 3.9 percent per year in 1979–91. Additionally, intermediate purchases' share of output climbed from an average of 56 percent to an average of 59 percent, which boosted the intermediate purchases effect.

Multifactor productivity growth can be viewed as a weighted average of the growth rates of labor productivity, capital productivity, and intermediate purchases productivity, where each weight equals the input's share of output. Of the three types of single-factor productivity, labor productivity grew the fastest between 1972 and 1991; at 3.1 percent per year on average, its growth rate far exceeded that of capital and of intermediate purchases productivity, which registered at –0.2 percent and 0.0 percent. (See table 2.) The average shares during the 1972–91 period were 28 percent for labor, 14 percent for capital, and 58 percent for intermediate purchases. The growth rates of capital and intermediate purchases productivity during 1972–91 mask the strikingly different performances of these measures in the 1972–79 and 1979–91 intervals. Both capital productivity growth (0.8 percent) and intermediate purchases productivity growth (0.6 percent) were positive in 1972–79 and both were much lower—in fact negative—during the following period; the capital productivity growth rate sank to –0.7 percent per year and the intermediate purchases productivity growth rate slid to –0.3 percent per year.

The cotton and synthetic broadwoven fabrics industry is one part of the textile mill products industry (SIC 22). In 1991, the broadwoven fabrics industry accounted for 21.3 percent of the value of shipments in the textile industry. There are several other major industries in the textile industry, including knitting mills, textile finishing (except wool), carpets and rugs, and yarn and thread mills. During the 1972 to 1991 period, multifactor productivity grew more rapidly (1.3 percent per year) in the entire textile mill products in-

Table 1. Average annual growth rates in multifactor productivity, output per employee hour, and related measures, cotton and synthetic broadwoven fabrics industry, selected periods, 1972–91

Measure	1972–91	1972–79	1979–91
Output per employee hour[1]	3.1	2.5	3.5
Multifactor productivity	.8	1.1	.7
Capital effect[2]	.4	.3	.5
Intermediate purchases effect[3]	1.9	1.2	2.3
Capital services	.0	.7	–.5
Employee hours	–3.3	–1.1	–4.6
Capital per employee hour	3.3	1.7	4.3
Intermediate purchases	–.2	.8	-.9
Intermediate purchases per employee hour	3.1	1.9	3.9

[1] Output per employee hour equals multifactor productivity plus the capital effect plus the intermediate purchases effect. Each measure presented in this table is computed independently. Therefore, the three components may not sum exactly to output per employee hour due to rounding.

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

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

dustry than it did in the broadwoven fabrics industry (0.8 percent). Both the textile and the broadwoven fabrics industries performed better in the 1970's than in more recent years. The textile mill products industry registered an average annual increase in multifactor productivity of 1.7 percent in the 1972–79 period and 1.0 percent between 1979 and 1991; the cotton and synthetic broadwoven fabrics industry recorded a growth rate of 1.1 percent in the earlier period and a rate of 0.7 percent in the later period. This pattern of slower growth after 1979 contrasts sharply to the performance of multifactor productivity in total manufacturing; multifactor productivity growth was quite low in the manufacturing sector in 1972–79 (0.3 percent annually), but it jumped to 1.2 percent in 1979–91.

Related measures

Output. During the 1972–91 period, output in the cotton and synthetic broadwoven fabrics industry declined at an average annual rate of 0.2 percent. In the 1970's, output expanded in the industry at a pace of 1.4 percent per year, on average, but then it contracted by 1.2 percent per year from 1979 to 1991. Production hit its low for the period in 1974 and its peak just 3 years later.

The cotton and synthetic broadwoven fabrics industry is composed of two four-digit industries: SIC 2211, broadwoven fabric mills, cotton and SIC 2221, broadwoven fabric mills, manmade fiber and silk (which will be referred to as "synthetic" in this article). Fabrics produced by the cotton broadwoven fabrics industry are made wholly or chiefly of cotton (by weight) and those produced by the synthetic broadwoven fabrics industry are made wholly or chiefly of manmade fibers and silk, so each industry manufactures "blends" of cotton and manmade fiber as well as fabrics that are made solely of one type of fiber. The fabrics are called "broadwoven" because they are woven fabrics of more than 12 inches in width. A separate industry, narrow fabrics mills (SIC 2241), manufactures fabrics with widths of 12 inches or less, such as fabric labels and ribbons and safety belt webbing. Although much of the output of the broadwoven fabrics industry is used by the apparel, automotive, and home furnishings industries, some of the products are finished and ready for consumer use. Among these products are sheets, pillowcases, terry towels, and bedspreads.[2]

In the 1970's, the shares of the two four-digit industries in the value of shipments of the broadwoven fabrics industry were fairly stable, with the cotton broadwoven fabrics industry accounting for about 40 percent of value of shipments and synthetics accounting for about 60 percent. Then in the 1980's there was a shift towards synthetics, with a peak share in total industry value of shipments of 68 percent being

Table 2. Multifactor and related productivity indexes in the cotton and synthetic broadwoven fabrics industry, 1972–91

(1987=100)

Year	Multifactor productivity	Output per employee hour	Output per unit of capital	Output per unit of intermediate purchases
1972	86.9	63.7	102.7	96.1
1973	90.5	57.3	95.4	112.8
1974	84.7	59.3	93.1	98.6
1975	86.3	65.5	91.4	97.2
1976	93.8	65.8	103.9	108.9
1977	95.6	75.4	112.7	103.3
1978	89.1	70.5	101.0	97.0
1979	93.6	75.8	108.4	100.1
1980	99.3	78.7	107.1	109.2
1981	92.1	80.8	101.9	96.3
1982	90.0	85.8	87.5	92.7
1983	96.3	93.0	99.9	97.5
1984	95.5	91.3	97.0	97.6
1985	93.8	94.9	88.9	94.7
1986	97.3	101.3	93.9	96.4
1987	100.0	100.0	100.0	100.0
1988	96.3	100.3	99.3	93.6
1989	98.3	104.3	99.5	95.3
1990	100.3	109.0	97.0	97.4
1991	101.3	114.9	99.1	96.2
Average annual rates of change (percent)				
1972–91	.8	3.1	–.2	.0
1972–79	1.1	2.5	.8	.6
1979–91	.7	3.5	–.7	–.3

reached in 1984. However, in recent years, there seems to be a shift back towards cotton in the broadwoven fabrics industry, as the synthetic share fell to 59 percent in 1991 and the cotton share climbed to 41 percent.[3] Cotton's popularity has been on the increase in general lately, with worldwide consumption at record levels. In the total U.S. retail market for clothing and home fabrics, cotton's share rose from 34 percent in 1975 to 50 percent in 1989.[4]

In the broadwoven fabrics industry, output has exhibited a cyclical pattern during the period of this study, though it clearly has been influenced by factors in addition to the business cycle. Broadwoven fabrics output was at low levels during the recessions of the mid-1970's and the early 1980's, but it rebounded strongly as the U.S. economy emerged from those downturns; production jumped by 12.5 percent from 1975 to 1976 and by 13.9 percent from 1982 to 1983.

At the beginning of the most recent recession, which started in 1990, output fell by 4.1 percent. At first glance, it looks as though output in the broadwoven fabrics industry leads the business cycle, in that output has fallen in each of the years prior to a recession (1973, 1981, and 1989). However, it appears upon further investigation that factors such as cotton prices and imports are responsible for those dips in output. Between 1972 and 1973, the price of cotton soared, driving up the cost of producing many kinds of broadwoven fabrics. Although nominal value of shipments in broadwoven fabric mills, cotton (SIC 2211), and in broadwoven fabric mills, synthetic (SIC 2221), rose in 1973, output fell by 9.1 percent because of hikes in the prices of the industry's products. In contrast, during each of the three recessions since 1972, nominal value of shipments decreased in both segments of the industry. The declines in output in 1981 and 1989 were almost certainly related to competition from imported textile goods. Textile imports to the United States rose significantly in 1981 and 1989.[5]

The bulk of U.S. production of textiles is destined for the nonapparel market (home furnishings and industrial uses) and the percentage of U.S. textile output flowing to the nonapparel market has risen over the years. As of 1973, 54 percent of fabrics made and sold in the United States were for the nonapparel market and by 1991, 63 percent of such fabrics headed for that market.[6] This increase is one consequence of the strong growth in imports of apparel and apparel fabrics that occurred in the 1980's. (See the section of this article on imports and exports for further discussion of imported textiles.)

Labor. Labor input, measured by employee hours, declined rapidly in the cotton and synthetic broadwoven fabrics industry between 1972 and 1991, at an average annual rate of 3.3 percent. In both subperiods, 1972–79 and 1979–91, employee hours also dropped, by 1.1 percent per year on average in the first period and by a quick 4.6-percent per year in the second. The drop in labor in the 1970's occurred as output was expanding, while the drop in the 1980's accompanied a contraction of output.

Employment in the cotton and synthetic broadwoven fabrics industry decreased markedly from 288,000 in 1972 to 160,000 in 1991. The number of employees in the industry reached a high of 293,000 in 1976 and has fallen in most years since then. Between 1972 and 1987, the number of plants in the industry rose from 719 to 737, even though employment tumbled by 35 percent.[7] However, many of the plants in operation in 1987 were quite small; 43 percent employed fewer than 20 workers. The number of plants with 20 or more employees decreased by 26 percent, from 568 in 1972 to 421 in 1987.

Production workers comprise the vast majority of employees in the broadwoven fabrics industry. In 1972, production workers made up 90 percent of the industry's work force and in 1991, the percentage was virtually unchanged, at 89 percent. These figures are substantially above those for total manufacturing, in which 73 percent of employees were production workers in 1972 and 68 percent were production workers in 1991.

The average hourly earnings of production workers in the cotton and synthetic broadwoven fabrics industry tripled from 1972 to 1991, rising from $2.75 to $8.73. In both years, the average wage in broadwoven fabrics was well below the average for all manufacturing, which was $3.82 in 1972 and $11.18 in 1991. The gap between the two narrowed over the period in relative terms, as average hourly earnings in broadwoven fabrics went from 72 percent of the manufacturing average to 78 percent.

Although production workers in broadwoven fabrics earned three times as much per hour in current dollars in 1991, compared with 1972, real average hourly earnings actually fell slightly, from $6.34 to $6.19 in 1982 dollars. This decline occurred despite the concurrent increase in output per employee hour of 80 percent for the industry. Historically, increases in output per hour in most industries have been associated with higher real wages in the long run, but in the past 20 years this relationship has not held in numerous manufacturing industries, including cotton and synthetic broadwoven fabrics. The reduction of 2 percent in real average hourly earnings in broadwoven fabrics was smaller than the 8-percent reduction experienced in total manufacturing in that time span. Also, during the entire period, the real wage of production workers in broadwoven fabrics remained within a narrow range, reaching a peak of $6.63 in 1978 and a low of $6.08 in 1982.

Women made up 42 percent of the work force in the cotton and synthetic broadwoven fabrics industry in 1991, compared with 33 percent in total manufacturing. Both of these percentages are higher than those in 1972, when women made up 40 percent of employees in broadwoven fabrics and 29 percent of employees in manufacturing.

Intermediate purchases. Intermediate purchases, which include materials, fuel, electricity, and purchased services, decreased at an average rate of 0.2 percent annually between 1972 and 1991, the same rate at which output lessened. From 1972 to 1979, intermediate purchases rose by an average 0.8 percent per year in the cotton and synthetic broadwoven fabrics industry; then, from 1979 to 1991, intermediate purchases dropped by 0.9 percent per year.

Expenditures on materials account for most of the cost of intermediate purchases in the broadwoven fabrics industry. As of 1972, materials represented 90 percent of total intermediate purchases cost, with purchased services far behind at 6 percent, electricity at 3 percent, and fuel at just 1 percent. By 1991, materials cost had declined to 84 percent of the cost of intermediate purchases, as services (10 percent) and electricity (6 percent) became more significant, and fuel was unchanged.

In 1972, raw cotton was by far the largest single component of materials cost, with a share of 32 percent, while purchased spun yarn (all fibers) was a distant second, with a 16-percent share. By 1987, the latest year of data availability in the study time-frame, purchased spun yarn had taken the number-one spot, with a share of 22 percent of materials cost, and raw cotton was next at 20 percent. Polyester fiber's share was third in both years; it equaled 14 percent in 1972 and 17 percent in 1987.

The prices of materials used in the cotton and synthetic broadwoven fabrics industry fluctuated between 1972 and 1991, increasing in 11 years and decreasing in 7 of the remaining 8 years. In the entire period, materials prices climbed at an average annual rate of 4.7 percent, so that they were over twice as high in 1991 as in 1972. Prices of materials used in the formation of broadwoven fabrics advanced much more quickly in the 1970's than in subsequent years—at an average rate of 8.9 percent per year in 1972–79, versus 2.3 percent per year in 1979–91.

Rising energy prices in the 1970's and early 1980's were reflected in the shares of intermediate purchases cost going toward fuel and electricity in the industry. From 1975 to 1986, 2 percent of intermediate purchases expenditures were for fuel, compared with 1 percent in both 1972 and 1991. Electricity costs doubled in proportion between 1972 and 1991, rising from 3 percent to 6 percent (which was slightly below the peak share of 7 percent reached in 1986).

Capital. Capital input was at virtually the same level in the broadwoven fabrics industry in 1991 as in 1972—its average annual growth rate was 0.0 percent in the period. Capital is measured as the flow of services from the capital stock, which consists of equipment; structures; land; and inventories of finished goods, work in process, and materials and supplies. Like intermediate purchases, capital increased in the 1972–79 period (at an average annual rate of 0.7 percent) and shrank in the 1979–91 period (at a rate of 0.5 percent).

Of the four categories of capital input, only the services of equipment increased between 1972 and 1991, at an average rate of 0.8 percent per year. In both of the subperiods, 1972–79 and 1979–91, the services of equipment also rose, by 1.9 percent per year in the first period and by 0.2 percent per year in the latter period. A significant part of the investment in equipment in the 1970's was necessitated by newly instituted Federal safety and health regulations regarding cotton dust and noise levels.

The other three categories of capital input (structures, land, and inventory) all declined in each of the periods being considered. The services of structures, which are the buildings used in the production process, dropped the fastest in 1972–91, at a rate of 1.4 percent annually. The capital input from inventories of finished goods, work in process, and materials and supplies decreased at 1.1 percent per year on average and the input from land (on which the structures sit) diminished by 0.8 percent per year. In the earlier years, 1972–79, the services of inventories descended at the swiftest rate (1.5 percent average per year); those of structures fell by 0.6 percent per year and land, by 0.1 percent per year. Then in the later years, 1979–91, inventories decreased at the lowest rate (0.9 percent) of these three types of capital input; land and structures both experienced steeper rates of decline (1.3 and 1.9 percent).

Imports and exports

Textile imports became a threat to the U.S. fabric and apparel industries in the 1980's. Import penetration into the U.S. textile market (including apparel and nonapparel textiles) was only 17 percent of the total domestic market in 1973 and 15 percent in 1979. By 1986, however, imports of textiles surged to 38 percent of the total U.S. market.[8] Most of the growth in imports was in the apparel and apparel fabric market, where the percent that is imported doubled between 1980 and 1986, from 28 percent to 56 percent. Much of the increase in textile imports was due to the strengthening of the dollar in the first half of the 1980's, which made imports cheaper. Also, competition from low-wage countries, such as China, contributed to the rise in imports of textile products. Even with the protection of the average 20-percent tariff on textiles, the cost of imported fabric and clothing can be much lower than the cost of domestic products, due to huge wage differences. For example, in a recent year, the average hourly wage for textile workers in China was only 37 cents.[9] With the value of the dollar declining in the late 1980's, the growth of textile imports slackened, and the percent of total U.S. textiles that were imported just climbed several percentage points to 43 percent in 1991.[10]

The enormous expansion of textile imports occurred despite the multi-fiber arrangement, officially known as the Arrangement Regarding International Trade in Textiles, which was adopted in 1974 under the auspices of the General Agreement on Tariffs and Trade and which has been renegotiated several times. The multi-fiber arrangement, a quota system for textiles and textile products implemented through a set of bilateral agreements, was designed to give domestic markets time to adjust to changing conditions resulting from import growth. Under the arrangement, annual quotas are set for covered products and the quotas are increased each year, with an overall minimum level of growth of 6 percent per year. While the restrictions of the arrangement have been used in the United States, the enforcement has not been viewed as very strict.[11] Also, compared with European quotas, U.S. textile quotas are very specific, and some exporting countries have been able to evade U.S. quotas by moving production into new lines that are not subject to quotas.[12]

The rise in textile imports in the 1980's affected the broadwoven fabrics industry as well as other portions of the domestic textile and apparel sector. Between 1980 and 1986, output in the cotton and synthetic broadwoven fabrics industry fell by 11 percent cumulatively and labor hours dropped by 31 percent. In the following 5 years, with the slowdown in import growth, output declined by 3 percent and employee hours, by 15 percent.

Exports account for a relatively small fraction of U.S. textile output, about 13 percent.[13] There has been significant growth in the value of textile exports (both apparel and nonapparel) since 1986. The value of those exports more than doubled from 1986 to 1991, after falling sharply between 1980 and 1986.[14] The export of broadwoven fabrics rose markedly between 1986 and 1991, from 334.6 million square meters in the earlier year to 566.4 million square meters in the latter.[15]

Technological developments

One of the biggest changes in the broadwoven fabrics industry in the past 20 years has been the massive shift to shuttleless looms. A mere 3 percent of the looms in place in U.S. broadwoven fabric mills were shuttleless in 1972. By 1991, 66 percent of looms in place were classified as shuttleless.[16] In traditional weaving, a shuttle, which is a wooden projectile, carries the filling or crosswise yarns (the weft) back and forth between the alternating sets of lengthwise yarns (the warp). The shuttle is "slam driven" by wooden bars from one side of the loom to the other. With shuttleless looms, various methods are used to move the filling through the warp. The four main types of shuttleless weaving machines are air jet, water jet, rapier, and projectile (also known as missile). As an example of how shuttleless looms function, air-jet looms operate by carrying the filling across the loom using high-pressure streams of air. Similarly, with water-jet looms, a jet of water takes the filling across the loom; however, water-jet looms are limited in that they can only be used to produce 100 percent synthetic fabric. Modern weaving machines are superior to shuttle looms in that they produce fabric of higher quality with fewer yarn breaks and they are faster, wider, and quieter. Because they are quieter, the shuttleless looms help companies to comply with Federal regulations regarding noise levels.

The popularity of air-jet weaving machines soared in the 1980's; the number operating in U.S. mills more than doubled between 1982 and 1989. Water-jet looms increased by 10 percent during that period and projectile machines, by 25 percent. The number of rapier looms decreased by 19 percent from 1982 to 1989, as earlier-generation rapiers were replaced with projectile machines and air-jet looms (as well as with some newer, faster rapiers). Later-generation shuttleless looms operate at much higher speeds than the older ones. An advantage of air-jet weaving machines is that they are generally less expensive to purchase and install than rapiers and projectiles. However, a drawback is that plants must also buy air compressors to use with air-jet looms. Even with that additional expense, air-jet looms can be cheaper to operate, because they are so productive. Their top operating speed is more than twice that of the rapiers and projectiles.[17]

While some plants in the broadwoven fabrics industry purchase yarn and then weave it into fabric, many plants begin with bales of fiber, which they transform into yarn that they then use for weaving.[18] Two major developments in yarn manufacture in the past two decades have been direct-feed carding and open-end (or rotor) spinning. In traditional yarn manufacturing, workers move fiber from machine to machine and in the process are exposed to high levels of cotton dust. With direct-feed carding, fibers are opened, blended, and carded in a continuous system, which lowers cotton dust generation and thus helps firms to meet Federal requirements for lower dust levels. (Carding is a process that initially parallelizes the fibers and turns them into a loose, rope-like strand.) Direct-feed carding is also much more productive than the older manual system.

Similarly, open-end spinning is a great deal more productive than conventional ring spinning. In yarn manufacture, the final stages are drawing, roving, spinning, and winding. In the drawing operation, several rope-like strands that result from the carding process are merged and the parallelism of their fibers is increased. The roving operation reduces the drawn strand to a smaller strand of fibers and adds a slight twist. In the spinning process, the fibers finally become yarn—the strand of fibers that emerges from the roving process is stretched and a twist is imparted. The last process, winding, transfers the yarn from the spinning bobbin to larger packages for weaving. In conventional ring spinning, the spinning bobbin is rotated on a spindle to insert the twist and put the yarn onto the bobbin. The size of the yarn package is limited and much power is necessary for its rotation. Open-end spinning machinery integrates the last three steps of the yarn manufacturing process. In addition to speeding up production, open-end spinning lowers cotton dust levels and noise levels in spinning rooms. Open-end spinning has not totally replaced ring spinning, at least in part because open-end spun yarns have different physical properties than ring-spun yarns.

In addition to technological developments in weaving and in yarn manufacture, advances in computer technology have had an impact on the broadwoven fabrics industry. Computer technology is playing a key role in "quick-response" programs, which are coordinated efforts to improve communications among fiber, textile, apparel, and retail firms. The primary goal of quick-response programs is to shorten, often by many weeks, the time between the placement of

Table 3. Output and input indexes in the cotton and synthetic broadwoven fabrics industry, 1972–91

[1987=100]

Year	Output	Combined inputs	Employee hours	Capital	Intermediate purchases
1972	97.3	112.0	152.7	94.7	101.3
1973	88.4	97.7	154.2	92.7	78.4
1974	87.4	103.2	147.4	93.9	88.6
1975	87.9	101.9	134.3	96.2	90.4
1976	98.9	105.4	150.3	95.2	90.8
1977	110.4	115.5	146.5	98.0	106.9
1978	99.9	112.1	141.7	98.9	103.0
1979	107.5	114.9	141.9	99.2	107.4
1980	107.6	108.4	136.8	100.5	98.5
1981	104.5	113.5	129.3	102.6	108.5
1982	90.8	100.9	105.8	103.8	98.0
1983	103.3	107.3	111.1	103.4	106.0
1984	100.8	105.5	110.4	103.9	103.3
1985	92.6	98.7	97.6	104.2	97.8
1986	96.1	98.8	94.9	102.3	99.7
1987	100.0	100.0	100.0	100.0	100.0
1988	97.8	101.6	97.5	98.5	104.5
1989	96.8	98.5	92.8	97.3	101.6
1990	92.9	92.6	85.2	95.8	95.4
1991	93.1	91.9	81.0	93.9	96.8
Average annual rates of change (percent)					
1972–91	–.2	–1.0	–3.3	.0	–.2
1972–79	1.4	.4	–1.1	.7	.8
1979–91	–1.2	–1.8	–4.6	-.5	–.9

orders by retailers and the delivery of goods to stores. Bar codes and electronic data interchange are important elements of quick response which facilitate communication between customers and suppliers at various levels. Systems for bar coding have been established by groups such as the Fabric and Supplier Linkage Council so that vendors can label shipments with standard bar codes and workers at the purchasing firm can scan the codes and enter the delivery immediately into inventory records. With electronic data interchange, a textile firm can communicate with its suppliers (such as fiber firms) and customers (such as apparel manufacturers) by using computers. At a large textile manufacturer which is a pioneer in quick response, purchase orders to their vendors are processed electronically. Additionally, the status of their customers' orders can be checked electronically by the customers themselves.[19]

There are numerous potential advantages from quick-response efforts. Among these is a reduction in inventory costs for textile mills, apparel manufacturers, and retailers. Also, better communication among the companies can drastically reduce warehouse time and in-process inventory. One textile firm, which specializes in upholstery and is on the forefront of quick response, has a customer in advance for every yard of fabric it weaves.[20] Other potential benefits of quick response include reductions in forced markdowns and in stockouts. Forced markdowns of prices occur when goods fail to sell as well as retailers expected. By reducing initial order time and reorder cycle times, forced markdowns can be decreased. Stockouts, which happen when a retail customer cannot find a particular size or style because it is out of stock, often result in lost business. By speeding up the replenishment of styles and sizes that are selling well, stockouts are diminished and sales are increased. A further possible advantage of quick response is that it can make domestically produced apparel and other textile products more appealing to retail firms than similar imported goods.

Quick-response programs are relatively new and there is a long way to go before they are widespread. Many technical and institutional barriers will have to be overcome if quick response is to become commonplace.

Another fairly recent development is the Textile/Clothing Technology Corporation, known as $(TC)^2$. $(TC)^2$ is a joint effort by the fiber, textile, and apparel industries, unions, and the Federal Government to improve the productivity and performance of those industries. The organization was originally called the Tailored Clothing Technology Corporation, and the first union and industry participants were connected with men's suit manufacturing. By late 1984, many other industries in the fiber-textile-apparel complex had gained representation by the corporation and the name was changed. Initially, $(TC)^2$ emphasized the development of technology that could revolutionize sewing. Lately, there has been more focus on helping smaller firms to use existing technologies better. $(TC)^2$ has also enhanced relationships between apparel companies and manufacturers of textiles and fiber.

Outlook

The current trend in textile manufacturing is to reduce greatly the number of workers necessary for the production process. There is a movement towards "lights-out" operations which are totally automated. In fact, fully automated open-end spinning has been achieved, in which spinning machines are run without operators. This "lights-out" process made its debut in 1991. Diagnostics and quality control systems help to ensure the quality of the output of totally automated open-end spinning machines.[21] Complete automation of the weaving process may be more difficult to attain, but it is "on the threshold of becoming a reality."[22] Automated repair of breaks in the filling (the crosswise yarns) is now a reality, with the use of electronics. However, warp repair might turn out to be the main stumbling block on the way to completely automated weaving that is economically feasible. One industry executive has said that he does not foresee the total elimination of weavers and does not expect to see fully automated repair of warp breaks because of the complexity of repair in terms of the location of breaks and the number of categories of breaks.[23]

Another trend likely to persist is the shift towards natural fibers, especially cotton. Apparel manufacturers have introduced permanent press all-cotton products in the past few years, which may intensify cotton's popularity. Cotton fabrics can be treated to be permanent press before or after the garment is constructed, but it is the "post curing" that is attracting the most attention, because a permanent crease and pleats can be put into the garment. Although at first limited to men's casual slacks, the use of permanent press cotton is now expanding to women's wear and men's dress shirts and slacks.[24]

International competition will continue to be a concern for the U.S. textile industry. While the growth of import penetration into the U.S. textile market slowed after 1986, the percent of the market captured by imports has risen each year since 1988, reaching 48 percent in 1993.[25] A positive trend for the cotton and synthetic broadwoven fabrics industry is that exports of broadwoven fabrics continue to climb.[26]

In an effort to make U.S. textiles more competitive, the American Textile Partnership (AMTEX) was begun in 1993. As a research agreement between the Department of Energy's national laboratories and the integrated U.S. textile industry, this partnership's purpose is to develop technologies for use by the industry. At least some of the technological developments are to be spin-offs of existing government technologies (such as those originally devised for the Department of Defense). More than 100 companies are involved in these projects.[27]

Lastly, quick-response programs are becoming more prevalent, as more retailers and apparel and textile firms discover their benefits. Annual conferences have been held in the past few years to educate companies on advances in quick response. Retailers are also starting to expand their quick-response efforts to include fashion items as well as basic goods.[28] While fashion goods may seem well suited to quick response because they are often marked down or out of stock, it can be more difficult to implement a quick-response program for fashion products than for basic products. One reason is that few domestic textile manufacturers have been producing short-run specialty fabric, which is needed for high fashion items.[29]

BETWEEN 1972 and 1991, multifactor productivity in the cotton and synthetic broadwoven fabrics industry increased by an average 0.8 percent per year. From 1972 to 1979, multifactor productivity experienced an average annual gain of 1.1 percent. In the subsequent period, 1979–91, the rate of growth was about two-thirds as large, at 0.7 percent per year.

Labor productivity, measured by output per employee hour, advanced at an average annual rate of 3.1 percent in 1972–91. The intermediate purchases effect, which equaled 1.9 percent per year, accounted for most of the difference between labor productivity and multifactor productivity. The capital effect, at 0.4 percent per year, explained the remainder of the difference.

If automation of the production process continues to increase and the pressures from international competition persist, the broadwoven fabrics industry could continue to see gains in multifactor productivity and losses in employment in the near future. Rising exports of broadwoven fabrics and the expansion of quick-response programs might boost production and diminish employment loss. □

Footnotes

[1] The Bureau of Labor Statistics also publishes multifactor productivity measures for two-digit manufacturing industries, for utilities industries and for three major sectors of the economy: private business, private nonfarm business and manufacturing.

[2] When these items are made in establishments other than weaving mills, they are classified in SIC 2392, Home furnishings, except curtains and draperies.

[3] The shares in total industry value of shipments were computed with data from the Annual Survey of Manufactures and the Census of Manufactures.

[4] "Cotton: Picked Again," *The Economist*, July 28, 1990, p. 59.

[5] *Textile Hi-Lights* (Washington, American Textile Manufacturers Institute, June 1994), p. 26.

[6] *Textile Hi-Lights*, (Washington, American Textile Manufacturers Institute, March 1993), p. 24 and *Textile Hi-Lights*, June 1994, p. 26.

[7] The latest year of data availability on number of plants in the study period is 1987.

[8] *Textile Hi-Lights*, March 1993, p. 24. Import penetration is calculated by dividing the amount of imported fabric by the total amount of fabric consumed in the U.S. market. The imported fabric is measured in square meter equivalents and includes the fabric in imported finished goods such as garments as well as bolts of fabric.

[9] Walecia Conrad, "The Textile Industry is Looking Threadbare," *Business Week*, Sept. 16, 1991, pp. 114–17.

[10] *Textile Hi-Lights*, June 1994, p. 26.

[11] U.S. Congress, Office of Technology Assessment, The *U.S. Textile and Apparel Industry: A Revolution in Progress - Special Report*, OTA-TET-332 (Washington, Government Printing Office, April 1987), pp. 85–86; and James L. Kenworthy, "U.S. China Textile Relations," *The China Business Review*, September-October 1991, pp. 40–44.

[12] MIT Commission on Industrial Productivity, "The US Textile Industry: Challenges and Opportunities," in *Working Papers of the MIT Commission on Industrial Productivity*, volume 2 (Cambridge, MA, The MIT Press, 1989), pp. 43-44.

[13] Conrad, "The Textile Industry is Looking Threadbare," p. 116.

[14] *Textile Hi-Lights*, June 1994, p. 27.

[15] *Textile Hi-Lights*, March 1993, p. 31.

[16] *Current Industrial Reports*, Series MQ-22T.1, June 1973 and Series

MQ-22T.2, June 1973, and Series MQ-22T, September 1992.

[17] "Air jets blow hot in the U.S. weaving market," *Textile World*, November 1989, pp. 42–43.

[18] The discussion of yarn manufacture in this paragraph is drawn from the following publications: Mark W. Dumas and J. Edwin Henneberger, "Productivity trends in the cotton and synthetic broad woven fabrics industry," *Monthly Labor Review*, April 1988, pp. 34–38; *The Impact of Technology on Labor in Four Industries*, Bulletin 2228 (Bureau of Labor Statistics, May 1985), pp. 18; and Office of Technology Assessment, *U.S. Textile and Apparel Industry*, pp. 42–44.

[19] Bernie Knill, "Quick Response: Now for the Hard Part," *Material Handling Engineering*, March 1990, pp. 67–78.

[20] Walter N. Rozelle, "Most Quick Response is foot dragging to Weave Corp.," *Textile World*, December 1990, pp. 79–82.

[21] McAllister Isaacs III, "Open-end spinning is ready for 'lights out,'" *Textile World*, November 1992, p. 44.

[22] Walter N. Rozelle, "Electronics accelerate weaving developments," *Textile World*, April 1992, p. 31.

[23] "Weaving features quick change, automation," *Textile World*, March 1993, p. 65–74.

[24] Raye Rudie, "Permanent Press Makes a Smooth Comeback," *Bobbin*, May 1993, pp. 66-70.

[25] *Textile Hi-Lights*, December 1994, p. 26.

[26] *Textile Hi-Lights*, March 1993, p. 31.

[27] John W. McCurry, "AMTEX Spurs New Ways of Thinking," *Textile World*, June 1994, pp. 78–82.

[28] Trevor Little, "Quick Response '92," *America's Textiles International*, May 1992, pp. 14–16.

[29] MIT Commission on Industrial Productivity, "The US Textile Industry: Challenges and Opportunities," p. 63.

APPENDIX: Measurement of multifactor productivity

Methodology and data definitions

The following is a brief summary of the methods and data that underlie the multifactor productivity measure for the cotton and synthetic broadwoven fabrics industry. A technical note, describing the procedures and data in more detail, is available from the author at the Office of Productivity and Technology, Bureau of Labor Statistics, Washington, DC 20212.

Output. The output measure for the cotton and synthetic broadwoven fabrics industry is based on the weighted change in the deflated value of shipments of various types of broadwoven fabric products, as reported in the Censuses and Annual Surveys of Manufactures. Deflated five-digit primary product shipments were Tornqvist aggregated using the values of product shipments as weights. This measure is in turn benchmarked to Tornqvist indexes of constant-dollar-production calculated from detailed quantity and value data published in the Census of Manufactures for 1972, 1977, 1982 and 1987.

For multifactor productivity measures for 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 multifactor productivity indexes BLS publishes for individual industries and those for aggregate sectors of the economy is that the latter measures are constructed within a value-added framework. For the major sectors of the economy, intermediate transactions tend to cancel out; intermediate inputs are more important in analysis of production at the industry level.

Further, output in the measures for individual industries is defined as total production that "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. Labor input is measured by an index of employee hours, which reflects the movements of the total number of employee hours. These hours are the sum of production worker hours and nonproduction worker hours. Production worker hours are from the BLS Current Employment Statistics (CES) survey; nonproduction worker hours are estimated by multiplying the number of nonproduction workers (from the CES survey) by an estimate of nonproduction worker average annual hours. The labor input data are the same as those used in the previously published BLS output-per-hour series for this industry.

Capital. A broad definition of capital input, including equipment, 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, for each type of asset, to take account of the loss of efficiency of the 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 relationship (in which efficiency declines more slowly during the earlier years) is chosen.

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

Intermediate purchases. Intermediate purchases 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 an 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 within the same company, or withdrawn from inventory during the year. An estimate of intraindustry transactions is removed from materials and fuels.

Annual estimates of the cost of services purchased from other business firms are also required for the measurement of multifactor productivity in a total output framework. Some examples of such 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.

Factor cost shares for capital, labor, and intermediate purchases. Weights are needed to combine the indexes of the major inputs into a combined input measure. The weights for the cotton and synthetic broadwoven fabrics industry are derived in two steps: first, an estimate of cost in current dollars for each input is derived, and then the cost of each input is divided by the total cost of all inputs.

Conceptual framework

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

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

$$Q(t) = Q[K(t), L(t), M(t), t] \tag{1}$$

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) totally with respect to time and then performing some algebraic manipulations yields the sources-of-growth equation:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + w_k \frac{\dot{K}}{K} + w_l \frac{\dot{L}}{L} + w_m \frac{\dot{M}}{M} \tag{2}$$

where $\dot{A}/A$ 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. (A 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 it is assumed that input and output markets are competitive and in long-run equilibrium, then each input is paid the value of its marginal product. In that case, the output elasticities can be replaced by factor income shares; that is,

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

where P_q is the price of output and P_k, P_l, and P_m, are the prices paid for the capital (K), labor (L), and intermediate purchases (M) inputs, respectively.

Furthermore, if constant returns to scale are assumed, then $w_k + w_l + w_m = 1$ and factor income shares are identical to factor cost shares.

Equation (2) can be rewritten as:

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

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 a contribution equation, which allows for an analysis of the change in output per hour. First subtract $\dot{L}/L$ from both sides of the equation. Then, because the weights sum to unity under the assumption of constant returns to scale, apply the term $(w_k + w_l + w_m)$ to the $\dot{L}/L$ term inserted on the right-hand side. Finally, collect terms with the same weight, to obtain:

$$\frac{\dot{Q}}{Q} - \frac{\dot{L}}{L} = w_k \left[\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right] + w_m \left[\frac{\dot{M}}{M} - \frac{\dot{L}}{L}\right] + \frac{\dot{A}}{A} \tag{4}$$

The left side of equation (4) is the growth rate of output per hour. The terms in brackets are the rates of change in the ratios of capital to labor and intermediate purchases to labor. Thus, the rate of growth in output per hour can be decomposed into the weighted sums of changes in these ratios plus the change in multifactor productivity.

Equations (2), (3), and (4) describe aggregation in continuous form. The BLS multifactor productivity indexes are constructed according to a Tornqvist formula that represents aggregation at discrete points in time and is consistent with a transcendental logarithmic production function. 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 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 $t - 1$.