Multifactor productivity in farm and garden equipment

Between 1958 and 1973, multifactor productivity played only a minor role in the growth of output per hour in this industry; after 1973, a substantial drop in multifactor productivity contributed to a decline in output per hour

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For almost a decade, the Bureau of Labor Statistics has published a labor productivity measure called output per employee hour for the farm and garden machinery industry. Many factors in addition to changes in the skills and efforts of the work force influence movements in labor productivity: technological change, economies of scale, the amount of capital input per worker, the amount of intermediate purchases input per worker, and other factors. Changes in these factors are reflected in shifts in the labor productivity measure. In this article, we present another measure of productivity for the industry—*multifactor productivity*—in which output is related to the combined inputs of labor, capital, and intermediate purchases.

The multifactor productivity measure differs from the traditional output-per-hour 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. It also allows us to separate effects—that is, to quantify the effects on labor productivity of changes in capital relative to labor and in intermediate purchases relative to labor. In the farm and garden machinery industry, there was a significant falloff in labor productivity in the post-1973 period relative to the pre-1973 period. Using results obtained from multifactor productivity calculations, this article examines the role played by the growth of capital and intermediate purchases relative to labor in the labor productivity slowdown after 1973.

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The Bureau of Labor Statistics first published multifactor productivity measures in 1983, covering the business sector, the nonfarm business sector, and the total manufacturing sector. Since then, measures have been published for 20 two-digit manufacturing industries and 4 three-digit manufacturing industries.

The farm and garden machinery industry, under Standard Industrial Classification (SIC) code 352,[1] produces farm machinery, such as tractors, harrows, plows, and haying machines, which accounts for about 64 percent of industry output. The industry also produces lawn and garden machines, such as mowers and tillers, accounting for the other 36 percent of industry output. Multifactor productivity in the farm and garden machinery industry showed a 0.1-percent annual growth rate, on average, during the period 1958–88. (See table 1.) This rate resulted from a 0.7-percent[2] average annual increase in output and a 0.6-percent rise in combined inputs. Capital input rose 2.5 percent per year, intermediate purchases gained 0.5 percent annually, and labor input fell slightly by 0.7 percent per year over this period. (See table 2.)

Labor productivity, that is, output per employee hour, in the farm and garden machinery industry increased at an average rate of 1.4 percent over the period. This growth rate was considerably below the manufacturing sector average increase of 2.6 percent.

Output per hour is the sum of the changes in multifactor productivity and the movements in capital and intermediate purchases relative to labor. The influence of changes in capital per

Table 1. **Multifactor and related productivity indexes, 1958–88**

[1982 = 100]

Year	Multifactor productivity	Output per hour	Output per unit of capital	Output per unit of intermediate purchases
1958	102.3	77.7	165.1	96.5
1959	101.6	77.5	172.4	94.5
1960	96.5	71.0	137.0	95.3
1961	99.1	74.4	150.1	95.3
1962	101.2	77.1	156.2	95.9
1963	101.1	79.5	164.8	92.8
1964	103.6	84.0	175.0	92.6
1965	104.7	86.6	175.8	92.9
1966	106.1	92.0	195.7	89.2
1967	102.9	91.6	172.4	88.4
1968	101.7	91.1	158.1	89.1
1969	98.2	87.3	142.7	87.8
1970	98.6	89.2	139.9	88.1
1971	102.0	96.4	141.9	89.7
1972	105.2	105.8	157.3	87.8
1973	108.5	109.9	168.6	89.0
1974	114.2	112.4	171.7	96.3
1975	108.5	111.9	153.6	91.4
1976	109.2	115.1	147.0	93.0
1977	108.3	113.8	146.8	92.1
1978	106.7	110.9	135.7	93.7
1979	108.8	111.4	155.8	91.4
1980	104.6	102.6	130.4	95.2
1981	101.6	103.4	124.7	91.5
1982	100.0	100.0	100.0	100.0
1983	97.1	98.2	93.2	98.4
1984	103.6	109.6	106.9	98.4
1985	99.1	103.6	95.9	98.5
1986	96.6	104.8	91.8	95.2
1987	104.4	112.9	106.5	98.9
1988	110.0	117.9	123.9	98.3
	Average annual rates of change (percent)			
1958–88	0.1	1.4	–1.7	0.2
1958–73	.2	2.4	–.3	–.7
1973–88	–.6	–.3	–3.7	.6

hour on labor productivity is referred to here as the "capital effect" and is measured by multiplying the change in the ratio of capital to labor by the share of capital costs in the total cost of output. The influence of changes in intermediate purchases per hour on labor productivity is described as the "intermediate purchases effect" and is measured by multiplying the ratio of intermediate purchases to labor by the share of intermediate purchases costs in the total cost of output.

While output per hour rose 1.4 percent per year, multifactor productivity grew only 0.1 percent, on average, over the period studied. The difference between the growth rates of the two measures is accounted for by increases of 0.6 percent per year in the capital effect and of 0.7 percent per year in the intermediate purchases effect. (See table 3.)

Output per hour rose fairly rapidly (2.4 percent) in the 1958–73 period, but fell off sharply to a 0.3-percent decline during the 1973–88 interval. (See table 4.) In the manufacturing sector as a whole, growth in output per hour fell from 2.8 percent to 2.7 percent between 1958–73 and 1973–88. (The rate had fallen to an average annual increase of 2.0 percent in the period 1973–79.) Signs of a reversal in the labor productivity slowdown have been evident in the manufacturing sector as a whole in the 1980's. (From 1979 to 1988, output per employee hour increased 3.8 percent.) By contrast, farm machinery showed a turnabout only during 1987 and 1988, partly because of a sharp and prolonged drop in demand in the early and mid-1980's. Output advanced at a fast pace (3.9 percent average annual gain) in the period 1958–73, but plunged to an average 5.2 percent decline per year during the post-1973 years. Hours posted a similar movement, increasing 1.5 percent per year during the earlier period, but falling off to a decline of 4.9 percent for the later interval.

Multifactor productivity rose slightly in the 1958–73 period (0.2-percent average annual gain), but slid to a 0.6-percent average annual decline during the post-1973 span. The slowdown between the two intervals was much smaller than the 2.7-percent falloff in labor productivity. The reason for this was that the growth rate in the consumption of intermediate purchases (which accounted for 53 percent of the total cost of inputs) fell off even faster than output.

The acceleration in the capital effect (the weighted change in the ratio of capital to labor) of 0.4 percent from the pre- to the post-1973 period partially offset the effect on output per hour of the falloff in multifactor productivity. Without this acceleration in the capital effect, the slowdown in output per hour would have been even greater than 2.7 percent. The improvement in the capital effect can be decomposed into changes in capital services, labor, and capital share weight. Growth in capital services slowed 5.7 percent, from an average of 4.2 percent in the pre-1973 period to –1.5 percent in the post-1973 period. The falloff in labor hours was even greater—from an average annual gain of 1.5 percent in 1958–73 to a decrease of 4.9 percent per year in 1973–88—thereby causing the ratio of capital to labor to improve over time. Because capital's average share in the value of total output remained about 20 percent, the capital effect increased from 0.4 percent in the earlier interval to 0.8 percent in the later span. Thus, changes in capital relative to labor did not contribute to the slowdown in labor productivity after 1973.

The intermediate purchases effect slowed substantially after 1973. The growth rate in intermediate purchases fell off between the two periods from a 4.6-percent average annual gain to a 5.7-percent average annual decline, for a total falloff of 10.3 percent. As mentioned earlier, labor hours decreased as well, but the slowdown of 6.4 percent in this measure was not as great. Therefore, the unweighted intermediate-purchases-per-hour ratio fell as well, from an average growth of 3.1 percent per year during 1958–73 to an average annual drop of 0.8 percent in the 1973–88 interval. With the intermediate purchases share of the value of total output averaging 53 percent for the 31 years analyzed, the changes in intermediate purchases relative to labor translated into a falloff in the intermediate purchases effect from 1.7 percent per year in the period 1958–73 to –0.4 percent annually during 1973–88. This falloff had a substantial impact on the labor productivity falloff. (See table 3.)

The falloff in intermediate purchases relative to labor from the pre- to the post-1973 period was probably influenced by changes in relative input costs. During 1958–73, labor costs per hour rose an average of 5.2 percent per year, while the prices of materials increased by less than half that rate (2.4 percent per year). This difference was an inducement for manufacturers to shift towards greater usage of materials relative to labor. After 1973, the gap between the two narrowed markedly as the rise in prices for materials (6.4 percent) was almost as great as that for labor costs (6.6 percent).

Output

Output in the U.S. farm machinery industry (SIC 3523) is influenced by several factors—among them, farm income, commodity prices, interest rates, farm land values, and competition from imports. When farm income and land prices are high and interest rates for borrowing are low, farmers tend to buy more new equipment; otherwise they repair the machinery they already own. These factors are quite cyclical and have caused wide swings in output for the industry over the period of the study.

Between 1960 and 1966, prices received for crops increased an average of 1.0 percent annually, which was reflected in a 2.4-percent average annual increase in gross income for farmers.[3] Farm and garden machinery output grew an average of 10.2 percent per year during the same period. Output fell 4.7 percent annually from 1966 to 1970, as a drop of 2.8 percent per year in prices for crops was recorded and an annual decline of 0.4 percent in gross income resulted for the 1966–69 period.

One of the largest jumps in the production of farm machinery took place between 1970 and 1974, when output increased an average of 13.6 percent annually. Pent-up demand for machinery, favorable interest rates, and an average annual increase of 18.9 percent in crop prices between 1970 and 1973 gave farmers added income with which to invest in new machinery. (Gross income grew 13.4 percent per year during the period 1970–73.) The high commodity prices were the result of poor harvests all over the world, grain deals with Russia, and a rise in specialty crop (for example, citrus products, nuts, and potatoes) farming.[4]

The production of farm machinery slowed again from 1974–78, with output declining an average of 3.1 percent. This drop was influenced by a fall of 2.6 percent per year in crop prices and the fact that manufacturers were trying to keep dealer inventories trimmed, especially because, in general, manufacturers pay

Table 2. **Output and input indexes, 1958–88**

[1982 = 100]

Year	Output	Combined inputs	Hours	Capital	Intermediate purchases
1958	80.0	78.1	103.0	48.5	82.9
1959	84.7	83.5	109.5	49.3	89.9
1960	68.3	70.7	96.1	49.8	71.7
1961	73.2	74.0	98.5	48.8	76.9
1962	78.4	77.5	101.8	50.3	81.7
1963	86.9	85.9	109.2	52.8	93.6
1964	97.4	94.0	116.0	55.7	105.2
1965	104.0	99.3	120.2	59.1	111.9
1966	124.2	117.2	135.0	63.6	139.4
1967	119.0	115.5	129.9	69.0	134.7
1968	114.0	112.1	125.2	72.2	128.1
1969	105.4	107.4	120.7	73.9	120.1
1970	104.0	105.4	116.5	74.4	118.1
1971	104.9	102.8	108.9	74.1	117.1
1972	122.8	116.8	116.1	78.2	140.0
1973	147.0	135.6	133.7	87.2	165.2
1974	165.9	145.2	147.7	96.7	172.4
1975	155.3	143.2	138.9	101.3	170.0
1976	152.5	139.7	132.5	103.8	164.2
1977	154.1	142.2	135.5	105.0	167.5
1978	142.5	133.6	128.5	105.1	152.1
1979	167.5	153.9	150.5	107.6	183.4
1980	140.5	134.4	137.0	107.9	147.7
1981	130.2	128.2	126.0	104.5	142.5
1982	100.0	100.0	100.0	100.0	100.0
1983	87.4	90.0	89.0	93.8	88.8
1984	96.8	93.5	88.3	90.7	98.3
1985	83.2	83.9	80.4	86.9	84.6
1986	74.6	77.1	71.3	81.3	78.4
1987	83.2	79.7	73.7	78.3	84.3
1988	96.9	88.1	82.2	78.3	98.7
	Average annual rates of change (percent)				
1958–88	0.7	0.6	–0.7	2.5	0.5
1958–73	3.9	3.6	1.5	4.2	4.6
1973–88	–5.2	–4.6	–4.9	–1.5	–5.7

Table 3. **Average annual growth rates (least squares method) in output per hour, multifactor productivity, and related measures, 1958–88, 1958–73, and 1973–88[1]**

Measure	1958–88	1958–73	1973–88	Acceleration or slowdown[4]
Output per hour . .	1.4	2.4	–0.3	–2.7
Equals				
Multifactor productivity	.1	.2	–.6	–.8
Plus				
Capital effect[2]	.6	.4	.8	.4
Plus				
Intermediate purchases effect[3].	.7	1.7	–.4	–2.1

[1]Each measure presented in this table is computed independently. Therefore, multifactor productivity, the capital effect, and the intermediate purchases effect might not sum exactly to output per hour, due to rounding.

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

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

[4]Obtained by subtracting the 1958–73 growth rate from the 1973–88 growth rate.

interest to dealers on floor inventories that go unsold. Output increased in the latter part of the decade, peaking with a gain of 17.5 percent between 1978 and 1979. Especially in those two years, growing conditions in other countries were poor, resulting in a 10.5-percent average annual increase in commodity prices for U.S. crops during 1978–79, which in turn caused a 5.3-percent average yearly increase in gross farm income for those years.

Abstracting from the short cycles, a major turning point in the industry's demand occurred after 1979: output, which had more than doubled during the period 1958–79, plummeted 56 percent between 1979 and 1986. This drastic decline had some cyclical elements to it. Interest rates soared in the late 1970's and early 1980's, commodity prices trended downward over the period, and prices for farm inputs such as fertilizer accelerated. For example, prices for fertilizers such as nitrogen and phosphate increased 7.2 percent annually, on average, between 1973 and 1979, up from an average decline of 1.0 percent per year during the pre-1973 period.[5] Between 1975 and 1982, average interest rates on total farm debt increased 50 percent, from 7.36 percent to 11.01 percent.[6] In addition, the Government's payment-in-kind program and the 1985 Farm Bill reduced the amount of land under cultivation, further depressing the demand for farm implements.

Other factors that have arisen since the late 1970's have depressed demand for U.S.-built farm machinery over the long term. For example, imports of farm machinery have grown dramatically, while exports have declined. Also, many farmers who expanded their operations rapidly in the early 1970's were forced out of business in the 1980's by the combination of low commodity prices and high interest rates. The effect was a substantial increase in the supply of used farm equipment, which the remaining farmers were able to purchase, thus deferring their purchases of new equipment.

In 1960, imports supplied only 7 percent of domestic consumption of farm equipment,[7] while exports equaled 12 percent of product shipments. Imports remained low for many years because U.S. technology was far ahead of that of the rest of the world in the development of self-propelled and large-capacity farm equipment, and foreign farm machinery manufacturers were not able to provide overnight repairs and replacement parts for their products, while American manufacturers could.[8] Such repair and replacement is crucial to farmers during planting and harvesting months, when machinery is in full use and more likely to break down.

The trade surplus remained throughout the 1960's and 1970's. But by 1979, U.S. manufacturers had stopped producing tractors under 40 horsepower because of increasing competition from Japan, where most such tractors are now made. Even the U.S. mainstay, the tractor over 100 horsepower, is now sharing the market with comparable models coming from Europe. By 1986, imports of farm equipment exceeded exports, and most of the exports were parts for equipment being assembled overseas. Imports as a percent of domestic consumption rose modestly—30 percent between 1972 and 1981—while the value of exports grew 170 percent—from $748 million to $2,019 million, in constant 1977 dollars—during the same period. From 1981 to 1988, imports as a percent of domestic consumption more than doubled, from 13.3 percent to 31.8 percent, while the value of exports fell 47 percent, from $2,019 million to $1,078 million, in constant 1977 dollars. The combination of the prolonged cyclical downturn and the surge in import penetration has caused the industry to shrink. Between 1982 and 1989, the number of major tractor producers in the United States plunged from seven to three, and only one remains independent.[9]

The 1980's began with the farm equipment industry's demand declining dramatically, but

its fortunes have brightened during the last 2 years of this study. There was a surge in the demand for farm machinery in 1988. Farm income grew 1.4 percent, on average, between 1986 and 1988, which allowed farmers to reduce their debt and invest in equipment. Prices received for crops grew 18.9 percent over 1987 levels, a result of lower crop surpluses caused by a drought in 1988. Farm land values increased for the first time since 1982, making more credit available to farmers. Average interest rates on total farm debt (real estate and otherwise) fell 1.3 percent, on average, from 1982 levels. Further improving the demand for farm equipment in 1988 was the fact that "much of the U.S. fleet of field farm equipment [was] old and not repairable, which limit[ed] the availability and sale of good used or rebuilt equipment."[10] As a result of all these factors, production increased 30 percent between 1986 and 1988.

Over the entire period 1958–88, output in the farm and garden equipment industry increased, on average, 0.7 percent per year. Much of this gain was stimulated by the increase in average farm size from 288 acres in 1959 to 453 acres in 1988. Larger farms are more able to benefit from utilizing larger, more sophisticated machinery. Most of the increase in output occurred during 1958–73, when output gained an average 3.9 percent per year. From 1973 to 1988, output fell by 5.2 percent, on average. The earlier period was characterized by a virtual U.S. monopoly on the production of farm machinery, while the recent span has shown a contraction and a restructuring of the industry due to the slow growth in farm income and the increasing penetration of imported farm machinery.

In sharp contrast to farm equipment manufacturing, output of lawn and garden equipment (SIC 3524) has been growing in the 1980's, thus becoming a larger portion of the value of shipments of industry SIC 352. In the early 1970's, lawn and garden machinery made up 18 percent of total industry shipments; by 1988, its share had risen to 36 percent. While farm machinery output fell a total of 44.7 percent between 1979 and 1988, lawn and garden equipment output grew 17.0 percent.

Home sales to the first-time purchaser, weather conditions, and financing costs affect the output of lawn and garden implements. First-time buyers of houses are usually in need of equipment such as lawn mowers, hedge trimmers, and, depending on the size of their property, other machinery such as snow throwers, mulchers, and plows, and they will typically purchase these items within the first year of homeownership. The garden equipment industry has been helped by the fact that the number of first-time home buyers has remained a fairly stable proportion of total home buyers (an average of 39 percent) between 1976 and 1988. The number of homes sold increased between 1970 and 1978, when it peaked at 3,986,000. After that, home sales dropped every year until 1982 and then moved back up to 3,594,000 in 1988.[11]

Weather conditions and financing influence those who already own equipment and are deciding whether to replace it. There has been a trend toward the purchase of more sophisticated, higher quality products, especially where servicing for the equipment is available. For example, even though electric mowers are cheaper, more consumers opt for gas-powered push mowers.[12] Sales of equipment such as tillers and garden tractors are more dependent on an area's income distribution and local geographic factors (for instance, a region's fertility) than are sales of push mowers, so annual sales of the former are quite stable.[13] In general, the demand for lawn and garden equipment is quite cyclical, with consumers replacing their machinery approximately every 5 years.[14] Because demand accelerated during 1984, the next growth spurt is not expected until the end of the 1980's.

The import-export situation for lawn and garden machinery is much brighter than for farm equipment. Competition from abroad has not yet made major inroads into U.S. markets.[15] Since 1986, the trade surplus in the lawn and

Table 4. **Average annual rates of growth in output per hour, hours, capital, intermediate purchases, and related measures, 1958–73 and 1973–88**

Measure	1958–73	1973–88	Acceleration or slowdown
Output per hour	2.4	–0.3	–2.7
Output	3.9	–5.2	–9.1
Hours	1.5	–4.9	–6.4
Capital	4.2	–1.5	–5.7
Capital per hour	2.7	3.6	.9
Capital effect[1]	.4	.8	.4
Intermediate purchases	4.6	–5.7	–10.3
Intermediate purchases per hour	3.1	–.8	–3.9
Intermediate purchases effect[2]	1.7	–.4	–2.1

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

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

garden equipment industry has been growing, partially due to the U.S. dollar's value having remained low in recent years, compared to other major currencies.

Labor

Employee hours declined at an annual rate of 0.7 percent in the farm and garden machinery industry during the period 1958–88. Hours increased at an annual average of 1.5 percent from 1958 to 1973, but fell by 4.9 percent per year, on average, in the post-1973 interval. The earlier period's increasing employee hours coincides with the increasing number of employees posted during that span, while total employment fell by 39 percent during 1973–88.

Multifactor productivity in the farm and garden machinery industry showed a 0.1-percent annual average growth during 1958–88.

The average number of weekly hours worked rose and fell along with the cyclical swings in output. In 1966, average weekly hours increased to 41.9, and they peaked in 1973 at 43.3. Average weekly hours reached their lowest point, 39.1, in 1982, and have been increasing ever since; by 1988, they had grown to 42.4.

The number of employees in the farm and garden machinery industry peaked in 1979 at 165,100. In 1988, it was 88,500, 28 percent less than in 1958. The average number of employees per plant fell from 74 in 1958 to 46 in 1987, and 70 percent of establishments had fewer than 20 employees per plant. Many of these smaller plants are producers of specialized farm equipment, such as dairy and poultry farming machinery, or contractors of specific parts for large manufacturers' tractors and combines. The actual number of plants in the industry increased from 1,469 in 1958 to 2,159 in 1977, but decreased to 1,799 in 1987.

Firms large and small have invested in new technology, which has decreased their labor requirements. Shortages of specialized craftworkers, especially welders, and increasing labor costs have helped spur the adoption of labor-saving technology. Between 1958 and 1978, wage rates, in constant 1977 dollars, grew 40 percent (an annual average increase of 1.7 percent). By contrast, every year since 1978, except for 1981, earnings per hour, in constant dollars, have fallen. The movement of earnings in the industry reflects that of total manufacturing, although the farm and garden machinery industry's average hourly rates always have been higher. In 1988, average hourly earnings in SIC 352 were $10.28 per hour, compared with $10.19 for total manufacturing. The $10.28-per-hour figure represents an average 0.4-percent-per-year increase over 1958 hourly rates. There was a slightly higher increase of 0.5 percent in average hourly wage rates in manufacturing as a whole during the 1958–88 period.

Declines in employment and closings of plants have been influenced by increasing imports. In 1986, imports exceeded exports for the first time in the history of the farm machinery industry. Imports were 32 percent of U.S. consumption in 1988, an increase from 4 percent in 1958. Exports increased as well, but at a much slower rate. In 1988, they were 29 percent of U.S. production, compared with 10 percent in 1958.

Capital

Capital is the flow of services derived from the equipment used in the production of farm and garden machinery; structures (plants housing the production process); inventories of finished goods, work in process, and materials and supplies; and the land on which the plants are located.

Thus defined, capital services grew at an annual average rate of 2.5 percent between 1958 and 1988. During the pre-1973 period, capital grew at an average annual rate of 4.2 percent, but it fell at a 1.5-percent annual rate, on average, during the 1973–88 period, a total falloff of 5.7 percent from the earlier period. This pattern followed that of output, although the drop in output has been more pronounced since 1973. Two periods of especially rapid growth in capital were 1962–68 (6.5 percent average per year) and 1971–74 (9.6 percent average per year). These spans coincided with periods of high output growth.

Between 1958 and 1988, capital structures and land moved similarly to overall capital, increasing at average annual rates of 2.8 and 3.0 percent, respectively. Equipment rose even faster, at an annual average rate of 4.1 percent. Inventories rose as well, but much more slowly (0.8 percent per year, on average). In the period 1958–73, equipment and land grew at a yearly average of 3.6 and 3.5 percent, respectively, while structures moved slightly more slowly (3.3 percent average per year). Inventories increased at a 4.9-percent annual average rate. Output increases were large during the mid-1960's, and by 1966, most plants were producing at capacity, so that in 1967 and 1968, manufacturers were purchasing more plant and equipment to keep up with expected production.[16] Inventories, which were needed to fill up depletions in 1965 and 1966, increased 22 percent between 1965 and 1968. A similar jump of 29 percent occurred between 1971 and 1973. By contrast, inventories have been reduced every year since 1975, except 1988, when they increased 8 percent over the 1987 level.

In the period 1973–88, three of the four capital inputs grew at a much slower rate than during

the earlier period; equipment was the exception. Inventories fell at an average annual pace of 6.2 percent, while structures rose by 2.8 percent per year, on average, and land by 1.5 percent. Equipment purchased by manufacturers continued to increase because of moves toward less labor-intensive production, more versatile machinery, and production to closer tolerances to compete with imports. Since 1982, all capital inputs have been declining—inventories at an average rate of 5.6 percent annually, equipment at 4.2 percent, structures at 2.8 percent, and land at 1.5 percent. The movements in capital reflect the severe contraction in the farm machinery industry in the 1980's.

(Data from the Department of Commerce's *Census of Manufactures*[17] on the gross book value of depreciable assets suggest that there were some premature retirements—that is, retirements prior to the end of service life—of capital assets in the farm machinery industry when output fell sharply in the 1980's. The equipment and structures components of the capital input measure presented in this article are based on the perpetual inventory method of computing them and thus do not reflect these premature retirements. Hence, the decline in capital input during the 1980's is somewhat understated. From 1980 to 1986, capital input, as measured here, fell by 25 percent. The data on the book value of assets suggest that capital in the farm machinery industry may have declined by as much as 33 percent over the period. The actual decline was probably not that much, because the productive efficiency of assets retired prematurely would have been considerably less than suggested by the book value data. That is, firms needing to reduce their stocks of capital would have prematurely retired the older capital, which would already have lost much of its productive efficiency, rather than retire new assets.[18])

Intermediate purchases

Intermediate purchases consist of raw materials, fuels, electricity, and purchased services. These inputs grew at an average annual rate of 0.5 percent between 1958 and 1988. The figure, however, masks the rapid average annual increase of 4.6 percent in the pre-1973 period and the subsequent dramatic fall of 5.7 percent per year, on average, in the post-1973 period, a falloff of 10.3 percent from the one period to the other. Intermediate purchases and output moved in the same directions in the pre- and post-1973 periods. However, intermediate purchases rose faster than output in the pre-1973 period and fell faster in the post-1973 period. In the earlier time span, output grew an average of 3.9 percent per year, 0.7 percent less than the rate for intermediate purchases. During the later period, output fell an average of 5.2 percent per year, 0.5 percent less than the decline in intermediate purchases. These trends are reflected in the intermediate purchases productivity variable, which rose slightly (0.2 percent) overall between 1958 and 1988. In the period 1958–73, this variable fell an average of 0.7 percent per year, when intermediate purchases grew faster than output, and in the period 1973–88, it increased 0.6 percent, on average. The latter upward movement was aided by efforts to reduce wastage of materials through the use of more efficient machinery and production techniques.

For example, computer-aided design and machining have made the production of prototypes for new parts obsolete, which has reduced the amount of aluminum required by manufacturers.[19] Similarly, flexible manufacturing systems allow machining centers to operate with a minimum number of steel sheet sizes or steel sheet coils, which has reduced material costs and wastage. The number of damaged or defective parts has decreased as well. One company found that the automatic unloading of machining centers with suction cups and magnets reduced the amount of damage to the surfaces of parts, which is very important for parts of combines.[20] Another firm, a manufacturer of specialized farm machinery, uses robots with pallet feeders to check finished parts. The robots catch flaws very quickly, so problems with machine settings can be corrected before too many defective parts are made. This firm has seen its rate of scrap parts decrease from 10 percent of finished parts to one-half percent.[21]

The 1980's began with the farm equipment industry's demand declining dramatically, but its fortunes brightened during 1987–88.

Materials make up 92 percent of intermediate purchases. Fuels account for 1 percent, electricity 1 percent, and services the remaining 6 percent. In 1987, the latest year for which detailed data are available, engines made up 35 percent of materials. Carbon steel was second with a 28-percent share, followed by castings with a 9-percent share, metal stampings with 7 percent, fabricated plastics products and speed changers, drives, and gears with 6 percent each, and pneumatic and semipneumatic tires with 5 percent. One of the materials used, diesel and semidiesel engines, showed a sizable increase of almost 35 percent between 1958 and 1977, but in 1982 a slight decrease occurred due to declines in demand. Demand recovered to its previous level in 1987. The overall dramatic rise in diesel engines used in the farm machinery industry was caused by a movement toward larger, more efficient machinery.

Consumption of intermediate purchases closely followed sharp swings in output. When

output increased 19.5 percent between 1965 and 1966, intermediate purchases reflected this increase with a 24.5-percent change. Both output and intermediate purchases fell between 1967 and 1971, at an average annual rate of 3.4 percent and 3.6 percent, respectively. During the farm machinery boom of the early 1970's, when output soared, intermediate purchases followed suit. From 1971 to 1974, output grew 16.8 percent per year, on average. To fulfill the need for materials for this increase in output, industry consumption of intermediate purchases grew at a 14.2-percent average annual rate between 1971 and 1974. As output fell off after 1974, intermediate purchases did so as well. From 1978 to 1979, output increased 17.5 percent and intermediate purchases grew by 20.5 percent. Both variables dropped steeply after 1979 until 1986, with a brief recovery in 1984, during which output increased 10.7 percent and intermediate purchases increased 10.8 percent over 1983. In 1987 and 1988, the farm and garden machinery industry registered a sharp upswing. (On average, output and intermediate purchases grew 14.0 percent and 12.1 percent, respectively, between 1986 and 1988.)

Over the period 1958–88, output in the farm and garden equipment industry increased, on average, 0.7 percent per year.

The prices of the materials used in the production of farm and garden machinery have increased steadily over the period studied. Prices for materials are of great importance to farm and garden equipment manufacturers because materials make up over 90 percent of intermediate purchases. These prices rose modestly (about 1 percent per year) until the late 1960's, when they accelerated somewhat. After 1973, they accelerated rapidly. Between 1973 and 1974, prices for materials rose 19.2 percent, and from 1973 to 1982, they rose at an average annual rate of almost 10 percent. The rapid growth provided a strong incentive for manufacturers of farm equipment to find ways of reducing materials requirements. Price increases slowed after 1982.

Technological changes

Technological innovation in the 1970's and 1980's has changed the way the farm and garden machinery industries manufacture their products. Processes have become more efficient and wastage has diminished. Because manufacturers vary greatly in the size of their operations, the rates of diffusion of new technology to individual plants differ.

Most of the investment in these industries in the last 20 years has been in computers, automation, and flexible manufacturing systems. Introduced in the late 1970's, flexible manufacturing systems are machining centers that contain a series of tools to produce finished parts from castings under the control of a computer system. Such an operation allows the production of anywhere from a few to hundreds of different parts to be made in any order the manufacturer chooses. When a new part has to be built, the computer program for the machine is changed; the process replaces the old method of manually resetting the machine every time. Flexible manufacturing systems have reduced the need for skilled machinists and conventional machine tools.[22] All of the recent innovations have cut production costs and work-in-process inventories.

The use of flexible manufacturing systems has had a significant impact on both the farm and lawn and garden machinery industries. Both produce low-volume output with multiple models for each product. For comparison, a farm machinery manufacturer produces fewer than 100 tractors per shift per plant, while the average automobile manufacturer makes 444 cars per shift per plant.[23] Before the use of flexible manufacturing systems, each month's demand had to be estimated for a specific model, production completed for that model, and the finished products put into inventory before work on the next model could begin. Now, with numerically controlled machining, computer-controlled assembly, and flexible design, a variety of models can be produced at the same time, thus reducing the level of inventories needed.

Numerically controlled machining allows for quick changes in tooling for different part dimensions for generically similar parts, thereby decreasing setup time. The operators control the tooling themselves. Even smaller manufacturers are looking into the production efficiencies of numerically controlled machines such as lathes, presses, and milling machines.[24]

Many of these machining lines are turned into manufacturing systems, known as "flexible machining system cells." For each "cell," a machine is loaded by an operator or an automatic loader, and then a computer controls the production of a part from machine to machine, until the part is finished. If the volume of production is very low, "cells" can easily be converted into individual machining centers.[25] Handling devices move the part between machines, and a computer controls the movement using computer numerical controls on each machine.[26] These systems reduce the labor time formerly required to transport parts manually from one station to the next. One company even has tools automatically dispatched to the machines according to the expected life of each tool. Warning signs on the machine inform operators when tools should be exchanged.[27] The "cell" system

has cut costs and improved quality.

Computers are a very important part of the manufacture of agricultural and garden implements. Dealers hooked up to plants electronically in the early 1980's, so when orders are sent to the factory electronically, computers set up production schedules. Inventories are controlled by computers as well, to eliminate shortages of parts and reduce work-in-process inventory. Purchasing departments are using computers to reduce their day-to-day duties of scheduling, resolving shortages, and keeping records, to allow them to spend more time negotiating and planning with vendors to reduce the cost of materials.[28]

Packaging is another function that has benefited from the use of electronic systems. To reduce the cost of packaging materials, computer programs were developed for one firm in the late 1970's to create a simple two-box storage and shipping system for parts. The computer plans the optimum number of parts per box. The system has saved the company $2 million.[29]

Computers are also being used to control the movement of assembly lines, permitting manufacturers to move products and their parts swiftly and allowing for flexibility in multiple model manufacturing.

Two of the most recent technological innovations are computer-aided design (CAD) and computer-aided machining (CAM). Introduced into the industry in the early 1980's, they have cut production costs dramatically. Flexible designing can now be done by computer, eliminating the need for time-consuming manually drawn plans. Changes to improve products can be inserted quickly, reducing product development time. Products can even be "tested" using CAD, so fewer prototypes need to be made. Finally, the CAD's dimensions can be reproduced accurately by the CAM system, so there are fewer problems with assembly and there is less wastage.[30]

Beginning in the 1970's, robots increasingly became a major part of the manufacturing process. Many are used in automatic welding because of the difficulty of attracting and retaining skilled welders. (Fumes are a health hazard for welders, and robots can be used for repetitive jobs while operators control the whole process.[31]) Robots now can do most of the painting of parts. Some assembly, forging, and forming lines also utilize robots to save on labor costs. Improvements in quality have been noted, and die changes on the robots are fast as well (15 minutes with a modern computer-controlled system, versus 2 hours using an older such system).[32]

Innovations can also be found in the welding and painting processes for farm and garden machinery. Electron beam welding has been introduced because of its ability to join high-strength steel. This type of steel is used more often in the industry because of the gigantic size of the new farm machinery being produced. In electrostatic painting, electrically charged parts are moved uniformly through spray booths with paint sprayed onto the parts. The paint bonds tighter and more uniformly to the electrically charged parts.[33] The result is thicker, more corrosion-resistant coats of paint.

Finally, the automation of materials handling was introduced into the largest plants in the late 1970's. Assembly plants are now serviced by automated storage, retrieval, and transportation systems. Components are stored in high-rise storage systems. When parts are requested through the storage computer, a crane is directed to the correct location, whereupon it picks the items out and then loads them onto an overhead conveyor, which, in turn, sends the parts to the location that requested them.[34] Conveyors move the product along the assembly line as each worker or robot completes an assigned job during the manufacturing process. Because computers control this assembly system, all required components and subassemblies get to the right place at the right time.

In the late 1980's, manufacturers of mowers and snow throwers started to employ a system similar to that used in the automobile industry. Called the "automated guided vehicle system,"[35] it permits components to be assembled on the vehicle as the vehicle moves down the assembly line. Parts are no longer moved between departments; rather, they are stored close to the point of assembly, so that a variety of models can be made at the same time. This configuration has eliminated shop floor scheduling, that is, the coordination of production of a piece of equipment between the departments that do the staffing, assembly, welding, painting, and so on, as a product is being manufactured.[36] The result is faster production.

Most investment in the industry in the last 20 years has been in computers, automation, and flexible manufacturing systems.

Lawn and garden equipment manufacturers were slower to adopt some of the emerging technological innovations of the 1970's than were farm machinery manufacturers because of the delay in the publication of the Consumer Products Safety Commission's mandatory safety standards for mowers. The Commission pushed back the publication of the standards until 1981 (7 years after they were scheduled to be announced), so the manufacturers delayed retooling their plants until they were certain what would need to be changed on the products they had already produced.[37]

During the early 1980's, the large manufacturers in the farm machinery industry boosted their investment in updated, automated, computer-controlled equipment. The new equipment enabled them to produce more at a lower cost, but because of the continuing slump in demand since the boom of 1978–79, firms that are still manufacturing agricultural implements are operating well below capacity, negating somewhat the cost savings and increased productivity the new technology was designed to bring them.

Summary

Output per hour in the farm and garden machinery industry grew at an annual average rate of 1.4 percent between 1958 and 1988. This growth can be accounted for by the growth in the capital and intermediate purchases effects (0.6 percent and 0.7 percent, respectively), as well as a slight 0.1-percent increase, on average, in multifactor productivity for the period. During 1958–73, output per hour grew an average of 2.4 percent per year, but it diminished to –0.3 percent in the post-1973 period. A substantial falloff in both multifactor productivity and the intermediate purchases effect played a role in the slowdown in output per hour.

A large drop in demand because of low commodity prices, low farm income, and increasing imports in the last decade has caused a decline in the farm machinery industry, which represented about 64 percent of SIC industry 352 in 1988. Relatively stable rates of household formation helped the lawn and garden equipment industry maintain its stability throughout the decade. Technological change in both industries—chiefly the introduction of computers, automation, and robotics—has improved quality while lowering the cost of both labor and materials. The sharp falloff in the growth of both labor and multifactor productivity in the post-1973 period reflects in part the industry's difficulties in adjusting to the severe decline in demand in the early and mid-1980's. □

Footnotes

[1] See Office of Management and Budget, *Standard Industrial Classification Manual* (Washington, Government Printing Office, 1987).

[2] All average annual rates of growth presented in this article are based on the least squares trend of the logarithms of the index numbers.

[3] Gary Lucier, Agnes Chesley, and Mary Ahearn, *Farm Income Data: A Historical Perspective*, Bulletin SB-740 (Washington, Department of Agriculture, Economic Research Service, 1986), pp. 17, 29.

[4] Keith W. Bennett, "Farm Machinery Set to Reap a Big '73," *Iron Age*, Nov. 16, 1972, p. 58.

[5] *Agricultural Resources: Situation and Outlook Report*, Bulletin AR-13 (Washington, Department of Agriculture, Economic Research Service, 1989), pp. 4–20.

[6] Lucier, Chesley, and Ahearn, *Farm Income Data*, p. 32.

[7] Domestic consumption equals product shipments plus imports minus exports.

[8] *United States Industrial Outlook, 1966* (Washington, Department of Commerce, 1965), p. 106.

[9] Kenneth R. Sheets, "Big Bruisers Come Back to the Farm," *U.S. News & World Report*, June 19, 1989, p. 51.

[10] *United States Industrial Outlook, 1990* (Washington, Department of Commerce, 1990), p. 23-2.

[11] *Statistical Abstract of the United States* (Washington, Bureau of the Census), 1977, p. 536; 1981, p. 771; 1988, pp. 484, 685, and 694; 1989, p. 716.

[12] Richard Carter, "Outdoor Power: Sales are Looking Up," *Hardware Age*, October 1981, p. 57.

[13] Carter, "Outdoor Power," p. 60.

[14] *United States Industrial Outlook, 1988* (Washington, Department of Commerce, 1988), p. 49-1.

[15] Leslie Eaton, "Riding to Recovery: After a Rough Patch, Murray Ohio Starts to Roll," *Barron's*, June 1, 1987, p. 46.

[16] *United States Industrial Outlook, 1968* (Washington, Department of Commerce, 1967), p. 177.

[17] Washington, various years.

[18] For a thorough discussion of premature retirements and their effect on the measurement of capital and multifactor productivity, see Susan G. Powers, "The role of capital discards in multifactor productivity measurement," *Monthly Labor Review*, June 1988, pp. 27–35.

[19] "How Toro Uses CAD/CAM to Stay Competitive," *Tooling & Production*, February 1986, p. 78.

[20] Gregory T. Farnum, "The X Factor," *Manufacturing Engineer*, March 1988, p. 88.

[21] Paul C. Miller, "Robots Build Rotary Mowers," *Tooling & Production*, March 1986, p. 92.

[22] James Cook, "Back to Simplicity," *Forbes*, Aug. 25, 1986, p. 32.

[23] *1988 Ward's Automotive Yearbook*, "U.S. & Canada '88 Model Assembly Plant Sourcing," p. 129. The automobile figure is calculated by averaging the number of cars built per hour by three major U.S. automobile manufacturers—General Motors, Ford, and Chrysler—and multiplying this average by 8 hours for one shift per plant.

[24] Keith W. Bennett, "Automation Trickles Down to Small Farm Equipment," *Iron Age*, June 23, 1980, p. 47.

[25] Keith W. Bennett, "Farm Equipment Makers Seek Faster Ways to Harvest Their Plants," *Iron Age*, July 27, 1981, p. 72.

[26] Keith W. Bennett, "Farm Equipment Adopts Flexible Manufacturing," *Iron Age*, Nov. 26, 1979, p. 142.

[27] "The Computer and John Deere: The Right Tool for the Right Job is the Rule for Computers at Deere," *American Machinist*, June 19, 1982, p. 138.

[28] Somerby Dowst, "Computer is Strategy Tool for Deere & Co.," *Purchasing*, vol. 96, Feb. 9, 1984, pp. 45, 51.

[29] "Computer Saves Dollars for Deere," *Modern Packaging*, October 1976, p. 25.

[30] "How Toro Uses CAD/CAM to Stay Competitive," *Tooling & Production*, Feb. 1986, pp. 75–78.

[31] "Welding for the '80s Heavy Vehicles: Farm Equipment," *Welding Design and Fabrication*, November 1980, pp. 165–67.

[32] Paul C. Miller, "Robots Build Rotary Mowers," p. 92.

[33] Clyde E. Witt, "Deere & Company Installs First Application of AGVS in Assembly Operation," *Material Handling Engineering*, November 1987, p. 50.

[34] *John Deere Tractor Works* (John Deere & Company, 1980), p. 6.

[35] Witt, "First Application of AGVS," pp. 46–48.

[36] *Ibid.*, pp. 46, 48.

[37] Jay Holtzman, "No More Business As Usual," *Hardware Age*, February 1977, p. 72.

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 farm and garden machinery industry. A technical note, more detailed, is available from the authors at the Office of Productivity and Technology, Bureau of Labor Statistics, Washington, DC 21210.

Output. The output measure for the farm and garden machinery industry is based on the weighted change in the deflated value of shipments of various types of farm and garden equipment, as reported in the Censuses and Annual Surveys of Manufactures. Deflated five-digit primary product shipments were Törnqvist aggregated using the values of product shipments as weights. This measure is in turn benchmarked to Törnqvist indexes of constant-dollar production calculated from detailed quantity and value data published in the Census of Manufactures for 1958, 1963, 1967, 1972, 1977, and 1982.

For multifactor 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 much more important in 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. Employee hours 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 the Census figures 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 measurements of productivity, 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 pattern (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. They reflect the implicit rate of return to capital, the rate of depreciation, capital gains, and taxes.[1]

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.

Income shares for capital, labor, and intermediate purchases. Weights are needed to combine the in-

dexes of the major inputs into a combined input measure. The weights for the farm and garden machinery 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 here 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 that describes the relation of the output to the inputs and on a formula for an index that is consistent with this production function.

The general form of the production function underlying the multifactor productivity measures is postulated to be

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

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, we obtain, after some algebraic manipulations, the sources-of-growth equation

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

where $\dot{Q}/Q$ is the rate of change of total output, $\dot{A}/A$ is the rate of change of multifactor productivity, $\dot{K}/K$ is the rate of change of input of capital services, $\dot{L}/L$ is the rate of change of input of labor services, $\dot{M}/M$ is the rate of change of input of intermediate purchases, 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 competitive input markets are assumed, then each input is paid the value of its marginal product. In that case, the output elasticities can be replaced by factor cost 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 $w_k + w_l + w_m = 1$.

Equation (2) can be rewritten as

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

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, we subtract $\dot{L}/L$ from both sides of the equation. Then, because the weights sum to unity, we apply the term $(w_k + w_l + w_m)$ to the $\dot{L}/L$ term inserted on the right-hand side. Finally, we collect terms with the same weight, to obtain

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

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 indexes are constructed according to a Törnqvist 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

$$lnQ(t) - lnQ(t-1)$$

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 $t-1$.

Footnote to the appendix

[1]For an extensive discussion of the measurement of capital, see *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, 1983).