Growth Accounting

The Solow growth model presents a theoretical framework for understanding the sources of economic growth, and the consequences for long-run growth of changes in the economic environment and in economic policy. But suppose that we wish to examine economic growth in a freer framework, without necessarily being bound to adopt in advance the conclusions of our economic theories. In order to conduct such a less theory-bound analysis, economists have built up an alternative framework called *growth accounting* to obtain a different perspective on the sources of economic growth.

We start with a production function that tells us what output Y_t will be at some particular time t as a function of the economy's stock of capital K_t, its labor force L_t, and the economy's total factor productivity A_t. The Cobb-Douglas form of the production function is:

$$Y_t = A_t \times (K_t)^{\alpha} (L_t)^{1-\alpha}$$

If output changes, it can only be because the economy's capital stock, its labor force, or its level of total factor productivity changes.

Changes in Capital

Consider, first, the effect on output of a change in the capital stock from its current value K_t to a value $K_t + \Delta K$—an increase in the capital stock by a proportional amount $\Delta K/K_t$. In this production function K_t is raised to a power, α, so we can apply our rule-of-thumb for the proportional growth rate of a quantity raised to a power to discover that the proportional increase in output from this change in the capital stock is:

$$\frac{\Delta Y}{Y_t} = \alpha \frac{\Delta K}{K_t}$$

Thus if the diminishing-returns-to-scale parameter α were equal to 0.5, and if the proportional change in the capital stock were 3%, then the proportional change in output would be:

$$\frac{\Delta Y}{Y_t} = 0.5 \times 3\% = 1.5\%$$

Changes in Labor

Now consider, second, the effect on output of a change in the labor force from its current value L_t to a value $L_t + \Delta L$—an increase in the capital stock by a proportional amount $\Delta L/L_t$. In this production function L_t is raised to a power, 1-α, so we can apply our rule-of-thumb for the proportional growth rate of a quantity raised to a power to discover that the proportional increase in output from this change in the labor force is:

$$\frac{\Delta Y}{Y_t} = (1 - \alpha) \frac{\Delta L}{L_t}$$

Thus if the diminishing-returns-to-scale parameter α were equal to 0.5, and if the proportional change in the labor force were 1%, then the proportional change in output would be:

$$\frac{\Delta Y}{Y_t} = (1 - 0.5) \times 1\% = 0.5\%$$

Changes in Total Factor Productivity

Last consider, third, the effect on output a change in total factor productivity. A proportional increase in total factor productivity produces the same proportional increase in output:

$$\frac{\Delta Y}{Y_t} = \frac{\Delta A}{A_t}$$

Thus if the proportional change in total factor productivity were 2%, then the proportional change in output would be:

$$\frac{\Delta Y}{Y_t} = 2\%$$

Putting It All Together

So if we consider a real-world situation in which all three—the capital stock, the labor force, and total factor productivity are changing—then the proportional growth rate of output is:

$$\frac{\Delta Y}{Y_t} = \alpha \frac{\Delta K}{K_t} + (1 - \alpha) \frac{\Delta L}{L_t} + \frac{\Delta A}{A_t}$$

with the first term $\alpha(\Delta K/K)$ giving the contribution of capital to the growth of output, the second term $(1-\alpha)(\Delta L/L)$ giving the contribution of labor to the growth of output, and the third term $(\Delta A/A)$ giving the contribution of total factor productivity to the growth of output.

Thus this equation is the key. If we know the proportional growth rates of output, the capital stock, and the labor force, and if we know the diminishing-returns-to-scale parameter a in the production function, then we can use this growth-accounting equation to calculate the (not directly observed) rate of growth of total factor productivity A, and to decompose the growth of total output Y into (i) the contribution from the increasing capital stock K, (ii) the contribution from the increasing labor force L, and (iii) the contribution from higher total factor productivity A.

One way to view this growth-accounting equation is that it allows one to break down growth into components that can be attributed to the observable factors of the growth of the capital stock and of the labor force, and to a *residual* factor—often, in fact, called the *Solow residual*—that is the portion of growth left unaccounted for by increases in the standard factors of production.

Changes in the Solow residual or (the same thing) total factor productivity can come about for many reasons. Economists often refer to total factor productivity as "technology," but if it is technology it is technology in the widest possible sense. Not just new ways of constructing buildings, newly-invented machines, and new sources of power affect total factor productivity, but changes in work organization, in the efficiency of government regulation, in the degree of monopoly in the economy, in the literacy and skills of the workforce, and in many other factors affect total factor productivity as well.

Moreover, total factor productivity also inherits errors in measurement. An overstatement of inflation because of a failure to take account of better quality in goods will reduce the measured growth rate of output without reducing the measured growth rates of the inputs of labor and capital, and so will lead measured total factor productivity to understate the truth.

An alternative—and in my view preferable—way of writing the growth-accounting framework puts the rate of growth of output per worker—the growth rate of output minus the growth rate of labor input—on the left-hand side, and notes that the key variables on the right hand side are then the growth rate of capital-per-worker and of total factor productivity:

$$\frac{\Delta Y}{Y_t} - \frac{\Delta L}{L_t} = \alpha\left(\frac{\Delta K}{K_t} - \frac{\Delta L}{L_t}\right) + \frac{\Delta A}{A_t}$$

This expression decomposes the growth of labor productivity into two terms: the first term $\alpha(\Delta K/K - \Delta L/L)$ gives the contribution of *capital deepening* to increased labor productivity, and the third term ($\Delta A/A$) gives the contribution of total factor productivity to the growth of labor productivity. Since we are usually at least as interested in the growth of standards of living and output per worker as in the growth rate of total GDP, this form of the growth-accounting framework is often more useful.

Applying the Growth-Accounting Framework

Let's use this growth-accounting equation to decompose the sources of economic growth in one concrete case: the United States over the past half century, 1948-2000. The table immediately below presents the results of such an analysis with the diminishing-returns-to-scale parameter α set equal to 0.4.

Growth Accounting for the United States, 1948-2000

	Annual Growth Rate of Y	Annual Growth Rate of Y/L	Contribution of K/L	Annual Growth Rate of A
1948-1973	4.0%	3.0%	1.2%	1.8%
1973-1995	2.7%	0.9%	0.8%	0.1%
1995-2000	4.2%	3.0%	1.1%	1.9%

(α = 0.4)

In the United States, the past half-century breaks down naturally into three periods: (i) the high productivity-growth high-investment period of 1948-1973, during which the capital-labor ratio grew at approximately 3% per year; (ii) the low productivity-growth lower-investment period 1973-1995, during which the capital-labor ratio grew at a slower rate of 2% per year; and (iii) the recent five-year period of 1995-2000, during which the capital-labor ratio grew at about 2.7% per year.

These fluctuations in the rate of capital accumulation are substantial: they correspond to a shift in the savings-investment flow as a share of GDP of three percentage points or so. The principal suspects for the fall-off in investment in the middle period are (i) the oil shocks of the 1970s, which discouraged investment in energy intensive technologies, and (ii) the large Reagan budget deficits of the 1980s. The post-1995 acceleration of investment and thus of the growth-accounting contribution of capital deepening comes from (i) the end of the era of budget deficits and (ii) a remarkably steep fall in the price of information-age capital goods, which means that the same nominal share of nominal savings in nominal GDP translates into much higher real investment as a share of real GDP.

More important, however, than changes in the contribution of capital deepening are changes in total factor productivity growth. The swings in the annual growth rate of A between the three periods are enormous.

What caused the productivity slowdown of the 1973-1995 period? Observers have pointed to four factors—oil prices, the baby boom, increased problems of economic measurement, and environmental protection expenditures—and there are no doubt others. But none of these factors seems large enough to account for the magnitude of the collapse in total factor productivity growth experienced by the United States. The causes of the productivity slowdown remain uncertain. The productivity slowdown itself remains a mystery.

What caused the productivity speedup after 1995? The natural candidate is the coming of the information age—the shifts in business organization and competition caused by the technological revolutions in data processing and data communications. Indeed, they did play a substantial role both in accelerating the rate of capital deepening and in boosting total factor productivity growth in high-technology sectors.

However, there is more to the story. A McKinsey Global Institute study concluded that the jump in productivity growth was overwhelmingly driven by six sectors—computer and other durable manufacturing, electronics, telecommunications, retail trade, wholesale trade, and securities brokerage,. The information technology revolution was *the* key to the boom in the first three sectors, and was *a* key but not the only key in the last three sectors. “Product, service, and process innovations… were important causes” as well. Increased competition to spur businesses to improve productivity, organizational changes to take advantage of the information technology revolution (like warehouse automation and information technology-based supply-chain management), and smarter government regulation of industry played important roles as well in the acceleration of productivity growth in the second half of the 1990s.

The Council of Economic Advisers' Analysis

The 2001 Edition of the *Economic Report of the President* (Washington: Government Printing Office, 2001) prepared by the President's Council of Economic Advisers [CEA] contains a more detailed and sophisticated analysis of the acceleration of labor productivity growth in the second half of the 1990s by 1.63 annual percentage points. The CEA first makes a (small) correction to labor productivity growth to remove that portion that they believe is attributable not to faster growth of potential output but to a higher level of actual output relative to potential output: that accounts for 0.04 percentage points of the growth acceleration, leaving (after rounding) 1.58 percentage points to be explained by the capital deepening and total factor productivity terms in the growth-accounting equation.

The conclusion of the CEA's analysis is that 0.38 annual percentage points of the growth acceleration were contributed by the effects of "capital deepening." (Curiously, high-technology information-age capital deepening contributed 0.62 annual percentage points, and other forms of capital deepening contributed minus 0.23 annual percentage points: the boom in computer investment was so large in the second half of the 1990s that the amount of other forms of capital per worker actually fell.)

This leaves 1.19 annual percentage points of the acceleration in the growth rate of labor productivity to be attributed to faster total factor productivity growth. Of this faster total factor productivity growth, the CEA attributes 0.18 annual percentage points to faster total factor productivity growth in the computer-manufacturing sector alone, and 1.00 annual percentage points to faster total factor productivity growth outside the computer sector. (A final factor, improvements in the economic quality of workers, plays no role in the acceleration of economic growth.)

TABLE 1-1.—*Accounting for the Productivity Acceleration in the 1990s*
[Private nonfarm business sector; average annual rates]

Item	1973 to 1995	1995 to 2000	Change (percentage points)
Labor productivity growth rate (percent)	1.39	3.01	1.63
Percentage point contributions:			
Less: Business cycle effect	.00	.04	.04
Equals: Structural labor productivity	1.39	2.97	1.58
Less: Capital services	.70	1.09	.38
Information capital services	.41	1.03	.62
Other capital services	.30	.06	-.23
Labor quality	.27	.27	.00
Equals: Structural TFP	.40	1.59	1.19
Less: Computer sector TFP	.18	.36	.18
Equals: TFP excluding computer sector TFP	.22	1.22	1.00

Note.—Labor productivity is the average of income- and product-side measures of output per hour worked. Total factor productivity (TFP) is labor productivity less the contributions of capital services per hour (capital deepening) and labor quality.
Productivity for 2000 is inferred from the first three quarters.
Detail may not add to totals because of rounding.

Sources: Department of Commerce (Bureau of Economic Analysis) for output and computer prices; Department of Labor (Bureau of Labor Statistics) for hours and for capital services and labor quality through 1998; and Council of Economic Advisers for the business cycle effect and for capital services and labor quality for 1999 and 2000.