5.2 Measuring the Growth of Total Factor Productivity

When people mention productivity, often what they are referring to is *labor productivity*, which is output per worker: $y = Y/L$. But this particular measure of productivity confounds the effects of capital accumulation and technological progress, both of which can raise output per worker. To see this point, suppose that output depends on capital and labor according to the familiar Cobb-Douglas production function:

$$Y = BK^{\alpha}L^{1-\alpha} \tag{5.1}$$

where the parameter B reflects the state of technology. Dividing both sides by L, we see that output per worker equals

$$y = Bk^{\alpha} \tag{5.2}$$

where $k = K/L$ is the capital stock per worker. According to equation (5.2), labor productivity y depends positively on the technology parameter B but also on the capital stock per worker k.

A better measure of productivity is the parameter B. This parameter tells us not just how productive labor is, but also how productively the economy uses all the factors of production. For this reason, B is called *total factor productivity*, or just TFP.

Our measure of economic growth is the growth rate G of output per person. Under the simplifying assumption that the population and labor force grow at the same rate, G is also the growth rate of output per worker. So from equation (5.2) we can express the growth rate as[1]

$$G = \dot{B}/B + \alpha\dot{k}/k \tag{5.3}$$

According to equation (5.3), the growth rate is the sum of two components: the rate of TFP growth ($\dot{B}/B$) and the "capital-deepening" component ($\alpha\dot{k}/k$). The first one measures the direct effect of technological progress, and the second measures

1. Taking natural logs of both sides of equation (5.2) we get

$$\ln y = \ln B + \alpha \ln k$$

Differentiating both sides with respect to time we get

$$\dot{y}/y = \dot{B}/B + \alpha\,\dot{k}/k$$

which is the same as equation (5.3) because $G = \dot{y}/y$ by definition.

the effect of capital accumulation. The purpose of growth accounting is to determine the relative size of these two components.

If all the variables in equation (5.3) could be observed directly, then growth accounting would be very simple. However, this is not the case. For almost all countries we have time-series data on output, capital, and labor, which allow us to observe G and $\dot{k}/k$, but there are no direct measures of B and α. Growth accounting deals with this problem in two steps. The first step is to estimate α using data on factor prices, and the second step is to estimate TFP growth ($\dot{B}/B$) using a *residual* method. These two steps work as follows.

First, we must make the assumption that the market for capital is perfectly competitive. Under that assumption, the rental price of capital R_k should equal the marginal product of capital. Differentiating the right-hand side of equation (5.1) to compute the marginal product of capital, we then get[2]

$$R_k = \alpha Y/K$$

which we can rewrite as

$$\alpha = R_k K/Y$$

That is, α equals the share of capital income (the price R_k times the quantity K) in national income (Y). This share can be computed from directly observed data once we observe the factor price R_k.

To conduct the second step of growth accounting we just rewrite the growth equation (5.3) as

$$\dot{B}/B = G - \alpha\dot{k}/k$$

which says that the rate of TFP growth ($\dot{B}/B$) is the residual left over after we subtract the capital-deepening term from the observed growth rate G. Once we have estimated α using factor prices, we can measure everything on the right-hand side. This measure of TFP growth is known as the *Solow residual*.

5.2.1 Empirical Results

From the national accounts it appears that wage and salaries account for about 70 percent of national income in the United States. In other countries the number is roughly the same. So to a first-order approximation the share of capital is about 0.3, and to get a rough estimate of TFP growth we can set α equal to 0.3. Using

2. That is, $R_k = \partial Y/\partial K = \alpha BK^{\alpha-1}L^{1-\alpha} = \alpha BK^{\alpha}L^{1-\alpha}/K = \alpha Y/K$.

this value of α and measures of capital stocks constructed from the Penn World Tables (Heston et al. 2002), we can break down the average growth rate from 1960 to 2000 of all OECD countries. The results are shown[3] in table 5.1. The first column is the average growth rate G of output per worker over this 40-year period. The second column shows the corresponding TFP growth rate estimated over that period, and the third column is the other (capital-deepening) component of growth. The fourth and fifth columns indicate the percentage of growth that is accounted for by TFP growth and capital deepening, respectively. As this table indicates, TFP growth accounts for about two-thirds of economic growth in OECD countries, while capital deepening accounts for one third.

Economists such as Jorgenson (1995) have conducted more detailed and disaggregated growth-accounting exercises on a number of OECD countries, in which they estimate the contribution of human as well as physical capital. They tend to come up with a smaller contribution of TFP growth and a correspondingly larger contribution of capital deepening (both physical and human capital deepening) than indicated in table 5.1. In the United States, for example, over the period from 1948 to 1986, Jorgenson and Fraumeni (1992) estimate a TFP growth rate of 0.50 percent, which is about 30 percent of the average growth rate of output per hour of labor input instead of the roughly 58 percent reported for the United States in table 5.1.[4]

The main reason why these disaggregated estimates produce a smaller contribution of TFP growth than reported in table 5.1 is that the residual constructed in the disaggregated estimates comes from subtracting not only a physical-capital-deepening component but also a human-capital-deepening component. Since the middle of the 20th century, all OECD countries have experienced a large increase in the level of educational attainment of the average worker, that is, a large increase in human capital per person. When the contribution of this human capital deepening is also subtracted, we are clearly going to be left with a smaller residual than if we just subtract the contribution of physical capital deepening. But whichever way we compute TFP growth it seems that capital

3. We thank Professor Diego Comin of the Harvard Business School for his help in compiling the capital stock estimates underlying this table.

4. Their table 5 indicates that on average output grew at a 2.93 percent rate and that labor input (hours times quality) grew at a 2.20 percent rate. It also indicates that 58.1 percent of the contribution of labor input came from hours, implying an average growth rate in hours of $(.581 \cdot 2.20 =)$ 1.28 percent and an average growth rate in output per hour worked of $(2.93 - 1.28 =)$ 1.65 percent. Their estimate of the residual was 0.50 percent, which is 30.3 percent of the growth rate of output per hour worked.

Table 5.1
Growth Accounting in OECD Countries: 1960–2000

Country	Growth Rate	TFP Growth	Capital Deepening	TFP Share	Capital Share
Australia	1.67	1.26	0.41	0.75	0.25
Austria	2.99	2.03	0.96	0.68	0.32
Belgium	2.58	1.74	0.84	0.67	0.33
Canada	1.57	0.95	0.63	0.60	0.40
Denmark	1.87	1.32	0.55	0.70	0.30
Finland	2.72	2.03	0.69	0.75	0.25
France	2.50	1.54	0.95	0.62	0.38
Germany	3.09	1.96	1.12	0.64	0.36
Greece	1.93	1.66	0.27	0.86	0.14
Iceland	4.02	2.33	1.69	0.58	0.42
Ireland	2.93	2.26	0.67	0.77	0.23
Italy	4.04	2.10	1.94	0.52	0.48
Japan	3.28	2.73	0.56	0.83	0.17
Netherlands	1.74	1.25	0.49	0.72	0.28
New Zealand	0.61	0.45	0.16	0.74	0.26
Norway	2.36	1.70	0.66	0.72	0.28
Portugal	3.42	2.06	1.36	0.60	0.40
Spain	3.22	1.79	1.44	0.55	0.45
Sweden	1.68	1.24	0.44	0.74	0.26
Switzerland	0.98	0.69	0.29	0.70	0.30
United Kingdom	1.90	1.31	0.58	0.69	0.31
United States	1.89	1.09	0.80	0.58	0.42
Average	2.41	1.61	0.80	0.68	0.32

accumulation and technological progress each account for a substantial share of productivity growth—somewhere between 30 and 70 percent each depending on the details of the estimation.

5.3 Some Problems with Growth Accounting

5.3.1 Problems in Measuring Capital, and the Tyranny of Numbers

One problem with growth accounting is that technological progress is often embodied in new capital goods, a fact which makes it hard to separate the influence of capital accumulation from the influence of innovation. When output rises, is it because we have employed more capital goods or because we have employed better ones? Economists such as Gordon (1990) and Cummins and Violante (2002) have shown that the relative price of capital goods has fallen dramatically for many decades. In many cases this decrease has occurred not because we are able to produce more units of the same capital goods with any given factor inputs but because we are able to produce a higher quality of capital goods than before, so that the price of a "quality-adjusted" unit of capital has fallen. For example, it costs about the same as 10 years ago to produce one laptop computer, but you get much more computer for that price than you did 10 years ago. But by how much has the real price fallen? That is a difficult question to answer, and national income accountants, having been trained to distrust subjective manipulation of the data, probably adjust too little to satisfy growth economists.

To some extent this problem affects not so much the aggregate productivity numbers as how that productivity is allocated across sectors. Griliches (1994) has argued, for example, that the aircraft industry, which conducts a lot of research and development (R&D), has exhibited relatively little TFP growth while the airline industry, which does almost no R&D, has exhibited a lot of TFP growth. If we were properly to adjust for the improved quality of modern aircraft, which fly more safely and more quietly, using less fuel and causing less pollution than before, then we would see that the aircraft industry was more productive than the TFP numbers indicate. But at the same time we would see that productivity has not really grown so much in the airline industry, where we have been underestimating the increase in their quality-adjusted input of aircraft. More generally, making the proper quality adjustment would raise our estimate of TFP growth in upstream industries but lower it in downstream industries. In aggregate, however, these two effects tend to wash out.

A bigger measurement problem for aggregate TFP occurs when a country's national accounts systematically overestimate the increase in capital taking place each year. Pritchett (2000) argues that such overestimating happens in many countries because of government inefficiency and corruption. Funds are appropriated for the stated purpose of building public works, and the amount is recorded as having all been spent on investment in (public) physical capital. But in fact much of it gets diverted into the pockets of politicians, bureaucrats, and their friends instead of being spent on capital. Since we do not have reliable estimates of what fraction was really spent on capital and what fraction was diverted, we do not really know how much capital accumulation took place. We just know that it was less than reported. As a result it is hard to know what to make of TFP numbers in many countries, especially those with high corruption rates.

A similar problem is reported by Hsieh (2002), who has challenged Alwyn Young's (1995) claim that the Eastern "Tigers" (Singapore, Hong Kong, Taiwan, and South Korea) accomplished most of their remarkable growth performance through capital accumulation and the improved efficiency of resource allocation, not through technological progress. Hsieh argues that this finding does not stand up when we take into account some serious overreporting of the growth in capital in these countries.

According to Young's estimates, GDP per capita grew in Hong Kong by 5.7 percent a year over 1966–92. Over 1966–90, Singapore's GDP per capita grew by 6.8 percent a year, South Korea's also by 6.8 percent, and Taiwan's by 6.7 percent. Growth in GDP per worker was between one and two percentage points less, reflecting large increases in labor force participation, but even the per-worker growth rates are very high in comparison to other countries.

Young adjusts for changes in the size and mix of the labor force, including improvements in the educational attainment of workers, to arrive at estimates of the Solow residual. For the same time periods as before, he finds that TFP growth rates were 2.3 percent a year for Hong Kong, 0.2 percent for Singapore, 1.7 percent for South Korea, and 2.1 percent for Taiwan. He argues that these figures are not exceptional by the standards of the OECD or several large developing countries.

Hsieh argues, however, that there is clearly a discrepancy between these numbers and observed factor prices, especially in Singapore. His estimates of the rate of return to capital, drawn from observed rates of returns on various financial instruments, are roughly constant over the period from the early 1960s through 1990, even though the capital stock rose 2.8 percent per year faster than GDP. As we saw in the neoclassical model, technological progress is needed in order to prevent diminishing marginal productivity from reducing the rate of return to capital when such dramatic capital deepening is taking place. The fact that the rate of return has not fallen, then, seems to contradict Young's finding of negligible TFP growth. The obvious explanation for this apparent contradiction, Hsieh suggests, is that the government statistics used in growth accounting have systematically overstated the growth in the capital stock. Hsieh argues that such overstatements are particularly likely in the case of owner-occupied housing in Singapore.

Hsieh also argues that instead of estimating TFP growth using the Solow residual method we should use the "dual" method, which consists of estimating the increase in TFP by a weighted average of the increase in factor prices. That is, if there were no TFP growth, then the marginal products of labor and capital could not both rise at the same time. Instead, either the marginal product of labor could rise while the marginal product of capital falls, a process that would take place if the capital labor ratio k were to rise, or the reverse could take place if k were to fall. Using this fact one can estimate TFP growth as the growth in total factor income that would have come about if factor prices had changed as they did but there had been no change in K or L. By this method he finds that in two out of the four Tiger cases TFP growth was approximately the same as when computed by the Solow residual, but that in the cases of Taiwan and Singapore the dual method produces substantially higher estimates. In the case of Singapore he estimates annual TFP growth of 2.2 percent per year using the dual method versus 0.2 percent per year using the Solow residual.

5.3.2 Accounting versus Causation

When interpreting the results of growth accounting, it is important to keep in mind that an accounting relationship is not the same thing as a causal relationship. Even though capital deepening might *account* for as much as 70 percent of the observed growth of output per worker in some OECD countries, it might still be that all of the growth is *caused* by technological progress. Consider, for example, the case in which the aggregate production function is

$$Y = A^{1-\alpha} L^{1-\alpha} K^{\alpha}$$

as in the neoclassical model, where technological progress is exogenous.[5] As we saw in chapter 1, A is the number of efficiency units per worker, and its growth rate is the rate of labor-augmenting technological progress.

Comparing this to equation (5.1), we see that it implies total factor productivity equal to

$$B = A^{1-\alpha}$$

which implies a rate of TFP growth equal to $1 - \alpha$ times the rate of labor-augmenting technological progress:

$$\dot{B}/B = (1-\alpha)\dot{A}/A$$

Now, as we have seen, in the long run the neoclassical model implies that the growth rate of output per worker in the long run will be the rate of labor-augmenting technological progress $\dot{A}/A$:

$$\dot{A}/A = \dot{y}/y$$

In that sense, long-run economic growth is caused entirely by technological progress in the neoclassical model, and yet the model is consistent with the decomposition reported in table 5.1, because it says that the rate of TFP growth is

5. And also, as we shall see later in this chapter, in the Schumpeterian framework once capital has been introduced.

$$\dot{B}/B = (1-\alpha)\,\dot{y}/y$$

Given the evidence that α is about 0.3, this last equation implies that TFP growth is about 70 percent of the rate of economic growth, which is consistent with the evidence in table 5.1.

Of course, once we take into account the accumulation of human as well as physical capital, then the estimated rate of TFP growth falls to about 30 percent of economic growth. But that is just what we would get from the preceding model if we interpreted K not as physical capital but as a broad aggregate that also includes human capital, in which case α should be interpreted not as the share of physical capital in national income but the share of all capital in national income. Simple calculations such as the one reported by Mankiw, Romer, and Weil (1992) suggest that this share ought to be about two-thirds of national income, in which case the preceding models would again be consistent with the growth-accounting evidence, since it would imply a rate of TFP growth of about one-third the rate of economic growth, even though again the model would imply that in the long run the cause of economic growth is entirely technological progress.

To see what is going on here, recall that the capital-deepening component of growth accounting measures the growth rate that would have been observed if the capital-labor ratio had grown at its observed rate but there had been no technological progress. The problem is that if there had been no technological progress, then the capital-labor ratio would not have grown as much. For example, in the neoclassical model we saw that technological progress is needed in order to prevent diminishing returns from eventually choking off all growth in the capital-labor ratio. In that sense technological progress is the underlying cause of both the components of economic growth—not just of TFP growth but also of capital deepening. What we really want to know in order to understand and possibly control the growth process is not how much economic growth we would get under the implausible scenario of no technological progress and continual capital deepening but rather how much economic growth we would get if we were to encourage more saving, or more R&D, or more education, or more competition, and so on. These causal questions can only be answered by constructing and testing economic theories. All growth accounting can do is help us to organize the facts to be explained by these theories.

5.4 Capital Accumulation and Innovation

In this section we develop a hybrid neoclassical/Schumpeterian model that includes both endogenous capital accumulation and endogenous technological progress in one model. As we shall see, it provides a causal explanation of long-